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RUDIMENTARY TREATISE

ON

LOCOMOTIVE ENGINES,

WITH REFERENCES TO

THE SEVERAL MODES OF CONSTRUCTION.

By G. D. DEMPSEY, C.E.,

AUTHOR OF THE 'PRACTICAL RAILWAY ENGINEER.'

With Illustrations.

LONDON: JOHN WEALE.

A

RUDIMENTARY TREATISE

ON THE

LOCOMOTIVE ENGINE

IN ALL ITS PHASES:

POPULARLY DESCRIBED,

WITH ILLUSTRATIONS FOR STUDENTS AND NON-PROFESSIONAL MEN.

BY G. DRYSDALE DEMPSEY, C.E.,

AUTHOR OF THE "PRACTICAL RAILWAY ENGINEER," AND OTHER WORKS.

Fifty-four Illustrative Explanatory Diagrams.

SECOND EDITION.

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PREFACE.

Now-a-days we are all railway travellers. Whereever we may want to go, beyond the limited sphere of that sociable vehicle commonly called the "'bus," we find we must take the "rail." A few years since, and it might be a matter of choice whether we would adopt the old and *safe* coach, or risk our bodies and limbs on the new fashioned railway. But this choice is no longer ours; and we can now select only between going by "rail" and stopping at home.

This limitation in our resources of travel, however, has not really detracted from its safety: railway statistics show how vastly the number of travellers has been augmented, while the dangers they incur have been reduced; and we may now commit ourselves to the express train, at forty miles per hour, with infinitely far less risk of a broken neck than we could, forty years ago, mount the "Age" or the "Wonder," and follow its leaders at one fourth of that speed.

Thus the Railway, and all things appertaining to it become interesting to the community generally;—we admire the stupendous bridges, and the long perspective of arches in the viaducts, revel in the stunning sensation of passing through an iron pipe, or shut our eyes to the dismal gloom of the tomb-like tunnel,—the

station becomes a pleasant scene of bustle and excitement, and the stoppage of ten minutes or less, generously accorded at the refreshment department, seems a season of rest and enjoyment far more acceptable than would a whole week's revelry under less pressing circumstances.

It is natural that the moving power of the train should elicit more wonder, and incite more enquiry than all the stationary grandeurs of the road over or under which it travels. A massive structure of masonry, however great, looks as if belonging to its position, and might, for aught it suggests to the contrary, have grown into its place, or have for ever occupied it; but a machine of metal fitted for motion, and capable of creating—and, with the simplest human assistance, of regulating—the power of *self-motion*, could never be mistaken for a fixture upon the site it may occupy; and inevitably suggests, even to the mind of childhood, "How does it move?"

To answer this question in a manner carefully devoid of technicalities, and at the same time to render complete general information to the popular student, are the purposes aimed at in the following little work, which it is hoped will be found fully instructive for the non-professional reader, and a solid foundation for the extended enquiries of those who desire further acquaintance with the theory and practice of locomotive steam machinery.

London, December, 1855.

CONTENTS.

RUDIMENTARY TREATISE

ON

THE LOCOMOTIVE ENGINE.

A LOCOMOTIVE ENGINE, followed by a train of carriages, always impresses the spectator as a remarkable exhibition of inanimate power. The familiar, but now ancient, spectacle of the mail coach, whirled along by its glowing team, was wont to excite admiration by its evidence of equestrian training and discipline; but the means of its movement were palpable, and reflection was scarcely prompted by the sight. Of two witnesses—one from the workshop, the other from the stable—the latter could probably the best appreciate the principles of the draught, and explain why the leaders and the wheelers were selected for their respective places; but the sight of a complicated and apparently cumbrous machine, moving itself under the mere direction of a human driver, forcibly overcoming not only its own inertia, but that of the many heavy carriages and trucks which helplessly follow in its chains, is a demonstration of mechanical agency which, however often it may be witnessed, arrests the attention in every instance, and leads the mind to contemplate the means employed, or to inquire what those means are.

Let us become such inquirers, and endeavour to ascertain those means. We have just seen a friend "off by railway;" and, having had to wait some time on the platform of the station, glanced at the hissing leader of the train, which by brazen plate proclaimed itself to be a "Hurricane," "Thunderer," "Meteor," or other symbol of speed and power. While stationary, we noticed the engine had six wheels,—

perhaps all of one size—and having a long horizontal bar of metal outside the wheels attached to the spokes of the three wheels on either side, the wheels being thus connected or coupled together. Beneath the engine, a bright fire-light gleamed near the hinder end; while, in front, puffs of steam were issuing and hissing with deafening noise. A variety of bars, rods, and other pieces of shining metal appeared to be fixed under the body of the machine; but the arrangement was too complicated to allow us to trace the connection between these and the wheels; and the belief in their utility was chiefly induced by seeing the engine-driver descend from his standing-place at the back of the engine, and caressingly wipe them with a handful of greasy rags. We noticed, however, that the whole machine appeared externally to consist of three portions, of different shapes and sizes. The front part, on the centre of which the chimney or funnel was placed, was curved on the top, had straight sides and bottom, and was larger than the long middle or cylindrical portion of the engine; while the back portion was again of increased width, and seemed to descend nearer the ground than the front. A door in this part of the apparatus was opened by the driver's assistant, or stoker, who flung in two or three shovels of coals from the tender; and we were thus prepared to understand the explanation of a bystander, that this hind part of the engine is called the *fire-box.* The central cylindrical part was also described to be the *boiler,* and the front portion the *smoke-box.*

But the second bell rings; the passengers are all seated, and the carriage-doors closed; the last shaking of hands has been hurried through an open window; the porters scour along the side of the train, and warn the friends on the platform to stand back; the driver jumps into his place, and—while the stoker releases the break from the wheels of the tender—turns a small handle and sounds the whistle, and by the movement of other handles starts the engine. The puffs of steam from below cease, and the hissing is succeeded by a

sound as of a giant panting for breath. Presently, his metal lungs seem forced into action, and the laboured sound gradually quickens into a rapid throb that dies away in the distance, like the pulsations of Hercules borne on the wings of the wind.

From the platform, let us turn to study the internal mechanism of the engine.

We all know, to begin with, that the machine is impelled by steam, which it produces within itself, being fed at intervals with the two ingredients of fuel and water from the tender. The former we have seen supplied by the stoker with a shovel; the latter is administered directly from the tender through a pipe, which is aptly termed the *feed-pipe*. We all know, also, that when water is so heated as to become steam, it expands in bulk and thus produces motion, which the *engine* converts to an useful purpose. In this elementary view, we are aware that all steam engines resemble each other, whether in the ponderous forms of *marine engines*, working paddles or giving revolutions to screws; of *stationary engines*, pumping up water for supplying towns and cities, or actuating the elaborate mechanism of manufactures; or of *locomotive engines*, drawing trains of enormous weight on iron roads at velocities which, in the times of mere animal agency, would have been deemed chimerical, if not fabulous.

Portable machinery, however, always involves considerations which do not arise in the designing of stationary apparatus. Thus, locomotive engines are limited in external dimensions and in gross weight; while for fixed engines the size and the weight are points rarely taken into account. In locomotives, moreover, it is necessary to provide the most extended space for the operation of heat for the production of power; and thus, while a large boiler and a single internal tube are admissible, and sufficient for generating steam for a stationary engine, a small boiler is imperative in a locomotive, and the required heated surface for the rapid creation of steam is obtained by introducing within the boiler a large number of small tubes.

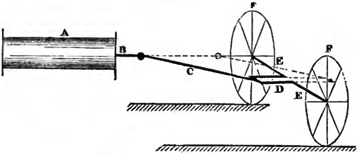
In short, the great desideratum in designing a locomotive engine is to obtain the greatest possible amount of power with the smallest possible size of the machine.

The most essential parts in all steam engines are the cylinder and the piston. We all know that the cylinder corresponds with the barrel of a pump, and that the piston is similar to the disc inside the pump, which the pump-maker calls the sucker. The common form of syringe, known by schoolboys as a *squirt*, is another instance of cylinder and piston familiar to all of us. We can readily understand how the expansion or swelling of the boiling water, as it becomes steam and is admitted within one end of a cylinder, will force the piston to the other end of it. We can also understand that if the steam be then let out of the cylinder, and fresh steam be admitted at the other end, behind the piston, the piston will be driven back again to the end from which it first started, and that these successive operations may be repeated, and the piston thus made to travel alternately from one to the other end of the cylinder.

We shall thus have produced what mechanics call a *reciprocating rectilineal* motion; that is, the piston will be moved backwards and forwards in a straight line.

The next purpose to bc accomplished is to make use of this motion for turning wheels round. Our piston is supposed to be provided with a piston-rod, which again corresponds with the rod of the pump and the handle of the syringe. This rod or handle is made long enough to project beyond the end of the cylinder at all times, for the purpose of connecting it with the next important part of the apparatus; viz., the *crank*. The wheels to be turned round are fixed on an axle; and this axle has a bend in it so formed, that while the two ends of the axle are in one straight line the bent portion is some inches out of that straight line. With the addition of a rod for connecting the piston rod with the crank, and which is hence called the *connecting rod*, our elementary apparatus will be completed, and we may now make a little sketch to assure ourselves that we understand it.

Fig. 1.



In this figure A is the cylinder with the piston within it, B the piston rod, C the connecting rod, D the crank on the axle E E of the wheels F F. The dotted lines show the position of the parts when the piston has reached the other end of the cylinder. The foot-lathe used by the turner, and the apparatus of the itinerant knife-grinder, are familiar examples of cranks for giving rotatory motion to wheels by the alternate movement of the treadles. Now, if we imagine a tea-kettle, sauce-pan, or any other closed vessel in which water may be boiled, to be so connected with the cylinder in our sketch that the steam shall enter alternately at each end of the cylinder, the steam being discharged at every *stroke* of the piston, or as soon as it has driven the piston from one end to the other, we shall have the entire motive mechanism of a locomotive steam engine. All the additions to be made to it, to convert it into the most complicated production of engineering art, consist of apparatus for boiling the water, for regulating the admission of steam into the cylinder, and the discharge of it from the cylinder, for providing adequate draught for the fire, and for giving to the driver of the engine the means of starting and stopping the movement of the engine, and of reversing the direction of its movement on the instant, as occasion may require.

A sketch of the history of the locomotive engine will show us the earliest forms in which it was designed, and the several improvements and additions made upon them; and by thus

watching the growth of the machine, step by step as it were, we shall readily trace the gradual progress from rude simplicity to the studied complication of parts which bewilder the eyes and the understanding of the uninitiated spectator of a modern locomotive.

The name which the world has learned to associate with the steam engine as a stationary machine, must also be quoted in reference to its birth as an apparatus for locomotion. JAMES WATT has recorded:—"My attention was first directed in 1759 to the subject of steam engines by Dr. Robison, then a student in the University of Glasgow, and nearly of my own age. Robison at that time threw out the idea of applying the power of the steam engine to the moving of wheel carriages, and to other purposes; but the scheme was not matured, and was soon abandoned on his going abroad."

This appears to be the earliest recorded notion of the locomotive steam engine, which Watt seems to have worked out into a practical form that he included in a patent obtained in the year 1784.

Watt's locomotive, as described in the specification of his patent, was to have a boiler formed of staves of wood bound with hoops of iron. An iron furnace was to be fixed within this boiler in such a manner that it should be nearly surrounded by water. The boiler and cylinder were to be fixed on a carriage having wheels worked by a piston moving a length or stroke of 12 inches within the cylinder, 7 inches in diameter. The same purpose, now usually effected with the *crank*, was, in Watt's locomotive, to be accomplished by *sun and planet wheels*, that is, by two cogged or toothed wheels, one of which would be fixed on the same axle as the wheels supporting the carriage, and the other made to revolve round it by the engagement of their teeth or cogs. The centre of the revolving wheel being connected with one end of the connecting rod and the piston-rod with the other end of it, the reciprocating motion of the piston would produce a rotatory motion of the carriage-wheels. Watt, however, having become

actively and profitably engaged in his improvements of stationary engines, did not prosecute the locomotive scheme; and WILLIAM MURDOCH appears to have been the earliest constructor of a locomotive steam engine. The date of this apparatus is recorded as 1784, the same year in which Watt's patent was obtained. Murdoch's locomotive, which can be regarded only as a toy, had a copper boiler with an oblique flue within it, and was heated by a spirit lamp. The piston had a stroke of 2 inches and was $\frac{3}{4}$ inch in diameter. The cylinder was fixed upright on the top of the boiler, and a connecting rod and crank, &c., were employed for giving motion to the axle of the driving wheel, or the *driving axle* (as it is called). The carriage is described to have been supported on three wheels, and the size of these wheels will convey a notion of the dimensions of the entire apparatus. The two wheels on the driving axle were $9\frac{1}{2}$ inches, and the third or leading wheel $4\frac{3}{4}$ inches, in diameter. This miniature engine was, however, provided with valves for regulating the passage of the steam, and is recorded to have beaten its inventor on one occasion when he wished to test its speed.

Eighteen years elapsed before any useful result was recognized as attainable by the application of steam to locomotive machinery. Murdoch's defeat by his three-wheeled toy might have suggested a practical purpose, in producing an enlarged and improved edition of it, but it does not appear to have done so; and to RICHARD TREVITHICK belongs the merit of having constructed the first experimental locomotive steam engine, and demonstrated its value as an instrument of draught. A patent was obtained, 24th of March 1802, by Richard Trevithick and Andrew Vivian, of Cornwall, for "methods of improving the construction of steam engines, and their application for driving carriages and other purposes." The experimental engine which was made according to this patent, and exhibited to the public in traversing the roadway near Euston Square, London, had four wheels,—viz., two small front wheels for guiding, and two larger hind wheels,—which received motion from

the steam. In accordance with his improvements in stationary engines, included in the same patent, Trevithick in his locomotive abandoned the idea of *condensing* the steam (which had been the great purpose of Watt's inventions), and adopted the *high-pressure* principle.* The engine had one cylinder, placed horizontally and enclosed with the boiler and furnace in a casing placed behind the axle of the driving wheels. The piston-rod was connected—not with the axle of the wheels, but with a separate axle, on which the crank was formed. The *crank-axle* was thus distinguished from the *driving-axle,* and the motion was imparted from the former to the latter by means of two toothed wheels of equal size—one on each of the axles, and which wheels were fitted or *geared* to work together. The *steam-cocks* for regulating the passage of the steam to and from the cylinder, were opened and shut by being connected with the *crank-axle.* A force-pump, for injecting hot water into the boiler, from the casing surrounding the cylinder, &c., was also worked with a rod attached to the crank-axle. In order to maintain the fire with sufficient activity for producing the required quantity of steam, bellows were provided, and were, like the cocks and pump, worked from the crank-axle.

In 1804, Trevithick placed another locomotive engine on a tram-road at Merthyr Tydvil, in South Wales, which engine differed in some respects from the experimental one just described. In the later engine, the cylinder was placed upright, or vertically, and the boiler was of cylindrical form with flat ends. A double or bent flue passed through the boiler, and the furnace and most of the cylinder were also within it. The cylinder of this engine was 8 inches in diameter, and had a stroke of 4 feet 6 inches. It drew a load of ten tons of bar iron, besides the trucks holding it, at the rate of five miles per hour, for a distance of nine miles, consuming only the water contained in the boiler at starting. In this engine the used steam was ejected into the chimney,

* See Rudimentary Treatise on the Steam Engine.

thus promoting the draught and dispensing with the bellows provided in the first engine of the same inventor.

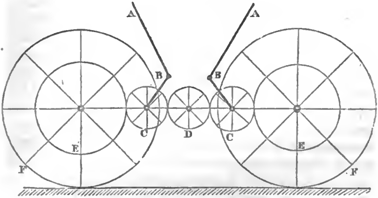
Trevithick's locomotive of 1804 does not appear to have been followed by any considerable improvement or alteration until the year 1811, when a patent was obtained, dated 10th April, by Mr. John Blenkinsop, for "certain mechanical means" of conveying coals, &c., which included the suggestion of a toothed wheel attached to the engine, to work in a rack to be fixed along one side of one of the rails of the road. This invention or adaptation was intended to obviate the inconvenience that had occasionally arisen from the *slipping round* of the wheels on the tramways without advancing the engine. This want of adhesion, or *bite*, of the wheels on the trams or rails was afterwards found to be remediable by an improved distribution of the weight on the wheels, which has rendered unnecessary the rack proposed by Blenkinsop, the chain by the Chapmans, and the automatic legs by Brunton, all of which expedients were devised to overcome the same supposed difficulty.

Blenkinsop's locomotive, however, is further noticeable as having first employed *two cylinders*, which worked alternately from the same *axle* or *shaft*.

In the year 1814, a locomotive engine was constructed at the Killingworth Colliery by the celebrated George Stephenson. This engine had two cylinders placed vertically, partly within and partly above the boiler, which was cylindrical, 8 feet long, and 2 feet 10 inches in diameter, with an internal flue 1 foot 8 inches in diameter. The cylinder was 8 inches in diameter, and the piston had a stroke of 2 feet. The connecting rods had cranks, each of which had a spur wheel fixed on its axle, and these spur-wheels gave motion to two other spur-wheels, one on either side, fixed on the axles of the carriage wheels. Between the spur wheels on the cranks of the connecting rods, a central spur wheel was provided, which was useful in preserving the cranks at right angles to each other, and in governing the effect of the pro-

pelling power. The spur wheels on the axles of the carriage wheels were 2 feet in diameter, and the three other spur wheels were each 1 foot in diameter, the arrangement being as here sketched:

Fig. 2.



In this figure, A A represent the two connecting rods from the piston rods, and B B the cranks on the axles of the spur wheels, C C; D is the central spur wheel, and E E are the spur wheels on the axles of the carriage wheels, F F. This engine is reported to have drawn 30 tons at the rate of 4 miles an hour, but the spur wheels were found to wear rapidly, and to make a great noise; and in the following year, Mr. Stephenson introduced an improvement which superseded the necessity for the spur gear altogether. This improvement was patented on the 28th February, 1815, by Mr. Stephenson in conjunction with Mr. Dodd, and the improvement is described to have consisted in "the application of a pin upon one of the spokes of the wheels that supported the engine by which it travelled upon the railroad, the lower end of the connecting rod being attached to it by what is termed a ball-and-socket joint; the other end of the connecting rod being attached to the cross beam, worked up and down by the piston." The patentees proposed two methods of keeping the cranks at right angles to each other; viz., to crank the

axle on which each pair of wheels was fixed, and provide a connecting rod between them, or to use an endless chain, of whieh the links should work into teeth of wheels fixed on the axles of the carriage wheels. In the engines constructed under this patent, either at the period of this date or subsequently, Mr. Stephenson discharged the used *steam into the chimney* for the purpose of aiding the draught of air through the furnace, and, consequently, the rapid production of steam. The immediate effect of this improvement is reported to have been the *doubling* of the speed of the engine.

On the 30th September, 1816, Mr. Stephenson, conjointly with Mr. Losh, obtained a patent for further improvements, which consisted "in sustaining the weight, or a proportion of the weight, of the engine upon pistons, movable in the cylinders, into which the steam or water of the boiler is allowed to enter, in order to press upon such pistons; and which pistons are, by the intervention of certain levers and connecting rods, or by any other effective contrivance, made to bear upon the axles of the wheels of the carriage upon which the engine rests. When, therefore, the steam presses upon the piston, the weight is transmitted to the axle by the piston rod, and the reaction of that pressure takes as much weight off the engine. If, therefore, the cylinders are of sufficient area, so that the pressure of the steam upon the whole of the pistons is equal to the weight of the engine, the engine will be lifted up, as it were, or entirely supported by the steam, which thus forms a kind of spring of the nicest elasticity."* The furnace was within the boiler of these engines, the endless chain was employed, and six wheels were used instead of four.

During the thirteen years which elapsed between 1816 and 1829, many minor improvements were introduced in locomotive mechanism. Mr. Stephenson substituted *coupling rods outside the wheels,* and connected to their spokes, for the endless chains he had previously used in the Killingworth

* Description by the Patentees.

engines; steel springs were introduced between the engine-frame and the axle-boxes; and tires of wrought iron were applied to the driving wheels.

It is recorded, that in the year 1825 locomotives were constructed upon eight wheels, arranged in two sets of four each, each set being attached to a separate frame, or *bogie.* Each of these frames was connected with the frame of the engine by means of a swivel joint, and thus great freedom was obtained for passing round sharp curves in the road, rail, or tram-way. The proposition for these bogie frames had been made in a patent obtained by Messrs. Chapman in the year 1812.

Mr. Stephenson's "Killingworth Engine," as it was used previous to the year 1829, had four wheels, 4 feet in diameter and coupled. The boiler, of wrought iron, was cylindrical, 4 feet in diameter and 9 feet long, with slightly convex ends. A fire tube, 1 foot 10 inches in diameter, was fixed within the boiler, the fire-grate being placed in one end of the tube, while the other end led into the chimney. Two cylinders were provided, sunk upright in the boiler, one at each end of it, and each cylinder, by means of piston-rod, connecting-rods, &c., worked one of the pairs of wheels. The performance of this engine, which weighed 6½ tons,—or with tender, fuel, and water, 10 tons,—was reported to equal 50 tons *gross* load—that is, including carriages or waggons, engine, and tender—at the rate of 6 miles per hour on a level, 15 cubic feet of water being evaporated per hour.

But the great desideratum for attaining *velocity* was yet wanting. Within the necessarily limited size for the locomotive boiler, means were yet required for boiling the water *fast enough* to produce the quantity of steam indispensable for rapidity of motion. The method for obtaining this object, which has since been so successfully adopted, was proposed by a French engineer, M. Seguin, in a patent in February, 1828. This method consisted in increasing the heating surface within the boiler, without increasing its exter-

nal dimensions, by inserting a great number of small tubes, through which the heated air circulates in streams, the water being contained in the boiler, and thus surrounding the tubes. The *evaporative power* of the apparatus was thus vastly augmented. This *multitubular flue boiler* (afterwards introduced to this country by Mr. H. Booth), added to the *steam-jet in the chimney* for promoting draught, completed the means of locomotive velocity, and these were the two distinguishing features of the successful "Rocket," the discharge of which in the year 1829 established the locomotive steam engine as the champion over all competing agents of conveyance, and cleared the air of the thick clouds of prejudice by which the merits of the infant railway system were at that period obscured.

The railway between Liverpool and Manchester was, at the time referred to, nearly completed; and the directors, anxious, of course, to obtain the most economical power for working their railway, were yet uncertain as to the instruments to be applied for securing that object. Horses had been suggested, and, as an improvement, stationary steam engines were proposed, which should draw the carriages with ropes or chains; but the results which had already been effected with locomotive engines induced the directors of the company to invite a competition for supplying the best form of such engine, and to offer a reward for the one which might the most successfully comply with certain conditions.

These conditions, as laid down by the directors on the 25th of April, 1829, were as follows:—

1. The engine should consume its own smoke.

2. An engine of 6 tons weight should draw 20 tons at 10 miles an hour, with a pressure of not more than 50 pounds.

3. Two safety valves to be provided, one beyond the reach of the engine driver.

4. The engine to have springs, and six wheels, and to be not more than 15 feet high to the top of the chimney.

5. The total weight of 6 tons to include water; but a less weight to be preferred, if drawing a proportionate weight; and an engine weighing only 4½ tons might be put on four wheels.

6. A mercurial gauge, to show the pressure above 45 lbs. to the inch, and to blow out at the pressure of 60 lbs.

7. The engine to be delivered in Liverpool, not later than the 1st of October, 1829; and,

8. The price of the engine to be not more than £500.

The time for delivery was afterwards extended to the 6th of October. The trial way was chosen at Rainhill, 9 miles from Liverpool, on a level portion of the railway, 2 miles in length. Five engines were named for the trial, but three only competed—viz., the "Novelty," by Messrs. Braithwaite and Ericson; the "Sans Pareil," by Mr. Hackworth; and the "Rocket," by Messrs. George and Robert Stephenson. The first two were disabled by accidents during the trial, and the "Rocket" was the only one that fulfilled the conditions, and was accordingly adjudged deserving of the £500 reward offered by the directors.

The "Rocket" was mounted on four wheels, not coupled or connected together. The boiler was cylindrical, 6 feet long, and 3 feet 4 inches in diameter, and contained *twenty-five copper tubes*, 3 inches in diameter, through which the *heated air* from the furnace passed on its way towards the chimney. The furnace, situated at the rear end of the engine, was 2 feet wide and 3 feet high, and had an external casing, between which and the fire-box a space of 3 inches was provided, and filled with water, communicating with the boiler. The two cylinders, placed one on each side of the boiler in an oblique position, were 8 inches in diameter, and the pistons had strokes of 16½ inches. The connecting rods from the piston-rods worked the front pair of wheels, which were about 4 feet 8 inches in diameter. The used steam was discharged into the chimney. The surface of the fire-grate was equal to 6 superficial feet; that of the fire-box

was 20 feet; and the total surface of the tubes exposed to the heated air was equal to $117\frac{3}{4}$ superficial feet. The weight of the "Rocket," including water in boiler, was 4 tons 5 cwt. The load consisted of a loaded tender, weighing 3 tons 4 cwt. and 2 lbs., and of two loaded carriages, weighing together 9 tons 10 cwt. 3 qrs. and 26 lbs., and making a total *drawn* weight of 12 tons 15 cwt., or a total weight of *train* equal to 17 tons. This engine attained the speed of 35 miles per hour without a load, and of 24 miles per hour drawing three times its own weight. Its average speed was reported at $13\frac{8}{10}$ miles per hour; consumption of coke per mile, for each ton of total weight of train, $\frac{91}{100}$ lb., or $11\frac{7}{10}$ lbs. for each cubic foot of water evaporated or turned into steam.

A comparison of the "Rocket" with the "Killingworth" engine shows that the former moved 40 tons at $13\frac{1}{3}$ miles per hour, while the latter moved the same weight at only 6 miles per hour.

Following the Rocket, Mr. Stephenson constructed seven or eight other engines for the Liverpool and Manchester Railway, and in each of these engines the heating flue surface was gradually extended from that of 25 tubes 3 inches in diameter, (in the "Rocket"), to 90 tubes of 2 inches in diameter; while the cylinders were increased from 8 to 11 inches in diameter.

While Mr. Stephenson was thus improving the locomotive engine and augmenting its power, other engineers were also busy in parallel courses of advancement; but most of the essential features of the "Rocket" were still retained, and improvements were directed to modifications of details, rather than to any alteration of its principal arrangements, or any addition to their number.

In the "Planet," however, the ninth engine built by Mr. Stephenson for the Liverpool and Manchester Railway, a happy combination was effected of all former good qualities, and the result was an engine which practically displayed several virtual improvements.

As this engine so far excelled all its predecessors that it

became the acknowledged model for succeeding engines, a brief description of it is necessary in this place:—

The "PLANET" was carried on four wheels; viz., two leading wheels 3 feet in diameter, and two driving wheels 5 feet in diameter. The boiler was 6 feet 6 inches long and 3 feet in diameter, containing 129 tubes, each $1\frac{5}{8}$ inch in diameter. The heating surface of the fire-box was equal to $37\frac{1}{4}$ superficial feet, and of the tubes 370 feet. The cylinders were 11 inches in diameter, and the pistons had a stroke of 16 inches. The weight of the engine, when empty, was 8 tons; or, with coke and water, 9 tons. The weight of the tender, including its load of coke and water, was 4 tons; or a total weight of engine and tender, charged, of 13 tons. The cylinders were horizontal, placed *inside the smoke-box*, and two cranks were provided on a separate axle for receiving the power. On the 4th December, 1830, the "PLANET" on its first trial took a train of 76 tons of passengers and goods from Liverpool to Manchester, in 2 hours and 39 minutes; its greatest velocity, on a level, being at the rate of $15\frac{1}{2}$ miles per hour.

The pattern of the inside cylinder engine, thus exhibited in the "PLANET," was immediately adopted, and was deservedly retained as the favourite model, from which succeeding engines departed only in details.

Our brief history of the locomotive engine thus brought down to the year 1851, and to the memorable epoch of the "Planet," here finds at once a resting-place for the previous, and a starting-point for the future, records of advancement. And we will, therefore, proceed to describe in detail the construction of locomotive engines, as practised for several following years. In this detailed description the present tense shall be observed, so that our readers may the more readily imagine themselves transferred to the period when most of the essential improvements had been practically displayed; and

from which period they may the more readily trace the subsequent course of extension of power and economy of steam.

The general order of description will be—

1. The Boiler, and the Manner of Generating the Steam, with the means of supplying the boiler, of cleaning it out, and of insuring its safety; also of ascertaining the pressure of the steam, and the quantity of water.

2. The Cylinders, and the Manner of Using the Steam, with the mode of supplying the cylinders with steam and working the pistons and slide-valves, and of moving the wheels and propelling the engine.

3. The Wheels, Framing, &c., of the Engine, with the springs, axle-boxes, and guides, &c., connected with the frame.

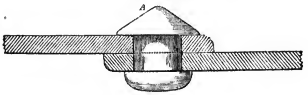
4. The Tender, for carrying coke and water to supply the boiler.

THE BOILER, AND THE MANNER OF GENERATING THE STEAM.

The boiler consists of several distinct parts: the cylindrical portion called peculiarly the boiler; the external fire-box communicating with it; the internal fire-box, containing the fire-grate; and the tubes, communicating between the internal fire-box and the smoke-box, upon which the chimney is fixed.

The Boiler is a cylinder 7 feet 6 inches long, and 3 feet 6 inches in diameter outside; it is made of wrought iron plates $\frac{5}{16}$ of an inch thick, lapping over each other, and joined

Fig. 3.



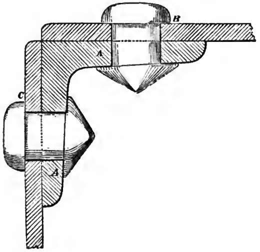
together by iron rivets $\frac{7}{8}$ of an inch in diameter and $1\frac{3}{4}$ inch apart, as shown in fig. 3, which is a section of a joint, half

size. The rivets are inserted red-hot, and contract in cooling, drawing the plates forcibly together, and making a very close joint.

The boiler is covered with wood one inch thick, put on in longitudinal staves, and bound round by iron hoops, which are screwed together at the bottom; this casing of wood is for the purpose of retaining the heat, and preventing it from being carried off by the air when moving rapidly through it, wood being an imperfect conductor of heat.

THE EXTERNAL FIRE-BOX is a box nearly square, 4 feet wide outside, and 3 feet $7\frac{1}{2}$ inches long in the direction of the boiler, made of wrought iron plates $\frac{5}{16}$ of an inch thick, like those of the boiler; the bottom is 2 feet 1 inch below the boiler, and the upper part is a semi-cylinder, concentric with the boiler. The fire-box is open at the bottom, and has a circular opening cut in the front side, of the same size as the boiler, and corresponding to it; the boiler being fastened to it

Fig. 4.



by means of angle iron, as shown in the section, half size, in fig. 4: the angle iron A is bent round the boiler at the place

of its junction with the fire-box, and riveted to the plates B and C of the boiler and fire-box. The plates composing the front and back of the fire-box are bent inwards at right angles all round, forming flanches upon which the plates of the sides and top are riveted.

THE INTERNAL FIRE-BOX is of similar shape to the external, but flat at the top, and closed at all sides except the bottom; a clear space of $3\frac{1}{2}$ inches is left all round between it and the external fire-box, and on the side next to the boiler the space is 4 inches. The internal fire-box is made of copper plates $\frac{7}{16}$ of an inch thick, except the side next the boiler, which is $\frac{7}{8}$ of an inch thick; but all of the plate except the circular portion opposite to the boiler is beaten down until it is only $\frac{7}{16}$ of an inch thick, the same as the rest. The roof and sides of the box are formed of one plate, and another plate forms the back, corresponding to that in the front next the boiler: the front and back plates are turned inwards at the edges, like those of the external fire-box, and the other plate fixed to them by $\frac{3}{4}$ inch copper rivets. The internal fire-box is fastened at the bottom to the external by setting the plates out until they touch the outer plates, and riveting them together with copper rivets. The plates are sometimes set out only so as to approach the outer plates within $1\frac{1}{2}$ inch, and a copper ring inserted between them, the rivets being put through the ring, and the joint thoroughly closed by hammering it up underneath; but it is generally found that the joint keeps water-tight best when made by setting the plates together and riveting them: a double row of rivets is generally used. An oval hole, 14 inches wide and 12 inches high, is cut in the back plate of both fire-boxes for the fire-door; the plate of the internal fire-box is set out all round it to meet the outer plate, and the two are fixed together by a row of copper rivets: a copper ring is sometimes inserted between the plates here, as well as in the joint at the bottom of the fire-box. The fire-door consists of two wrought iron plates connected together by rivets, leaving a space of $\frac{1}{2}$ inch between them: this pro-

tects the outer plate from the fire, and prevents it from getting too hot.

The fire-grate is fixed 3 feet 2 inches below the roof of the fire-box, and 9 inches above the bottom, and is composed of separate loose bars of wrought iron, $2\frac{1}{2}$ inches deep in the middle, and 1 inch thick at the upper side, tapering downwards to allow more free ingress for the air: the fire-bars are bent down at the ends and drop into holes in a square ring of iron, which runs round the fire-box at a little distance from the side, and is supported by a piece of angle iron, bolted to the front and back plates of the fire-box. The fire-bars are made separate and moveable, in order that they may be easily replaced when worn out, which happens very frequently from the great heat to which they are exposed; and also for the facility with which the fire can be extinguished in case danger should be apprehended from any accident; for by lifting them out of the holes with a bent rod, kept for the purpose, they can be dropped, together with the whole of the fire, upon the road: this is, indeed, the manner in which the fire is extinguished when the engine has done working. An ash-pan is fixed under the fire-box in some engines, made of sheet iron, of the same shape as the external fire-box, and open only in front; it serves to catch the cinders and prevent their falling on the road, but is rather inconvenient when the fire has to be let out.

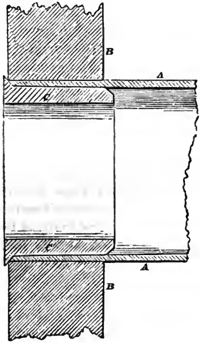
The boiler, being cylindrical, has an equal strain in all directions from the pressure of the steam; but as the fire-boxes are flat on all sides except the top of the external one, they would have a tendency to be separated from each other by the pressure of the steam, if they had not some support. For this purpose they are connected together by a number of $\frac{3}{4}$ inch copper bolts, which are screwed along their whole length and are passed through holes in both plates, tapped to receive them, and then riveted over at the ends for additional security: these copper bolts are screwed in about 4 inches apart all over the sides and back of the internal fire-box and that portion of the front that is below the boiler. As the roof of the internal

fire-box only requires support, that of the external one being cylindrical, it is strengthened by six wrought iron ribs, placed parallel to each other and longitudinally upon the roof, and fastened to it by bolts screwed through the roof-plate, and having, in addition, a nut screwed on at the under side: the ribs are $1\frac{1}{2}$ inch thick, and increased at the bolt-holes, and $2\frac{1}{2}$ inches deep at the middle, where the strain is greatest. The ribs are cut away on the under side between each of the bolts, so as to touch the roof-plate only where the bolts pass through them, in order that there may be as little mass of metal as possible exposed to the immediate action of the fire; for when a considerable thickness of metal is interposed between the water in the boiler and the fire, the heat cannot be absorbed by the water with such rapidity as it is supplied, and the metal becomes in consequence greatly heated, and is rapidly destroyed. The durability of the internal fire-box depends very much on the care of the engine-man: with proper use it will last several years, but if the water is allowed to get too low in the boiler, so as to have but little depth over the roof, the plate will be liable to get frequently uncovered, from the motion of the engine, and be rapidly destroyed. To prevent this accident, a small plug of lead is put through a hole in the centre of the roof of the fire-box, and riveted over on both sides: when the water gets so low as to uncover this plug, it is melted by the heat, and the steam, rushing into the fire-box, extinguishes the fire. The internal fire-box is made sometimes of wrought iron, and is generally found to last nearly as long as a copper one; the iron fire-box costs considerably less, but requires more care in using, and is very liable to crack and become leaky at the joints.

Tubes.—The communication between the fire-box and the chimney is made by a number of tubes, which are fixed water-tight at one end into the front plate of the fire-box, and at the other into the plate which closes the front end of the boiler; the tube plate of the fire-box being made thicker where the tubes are inserted, to allow for its being weakened by the holes

cut in it. There are 124 of these tubes; they are $1\frac{5}{8}$ inch in diameter outside, and a space of $\frac{3}{4}$ of an inch is left between them. They are made of the best rolled brass, $\frac{1}{13}$ of an inch thick (called No. 13 wire-gauge); the edges of the brass are properly chamfered and lapped over each other and soldered together, the solder being applied inside: the tubes are then drawn through a circular steel die, to make them truly cylindrical. The holes to receive them in the tube plates are bored quite cylindrical, so as to fit the tubes exactly, which are just long enough to come to the outside of both plates: the ends of the tubes are then fixed by driving in a steel hoop or ferrule, made slightly conical, as shown in fig. 5, which is a section,

Fig. 5.



full size, of the tube A A, the plate of the fire-box B B in which it is inserted, and the ferrule C C: the ferrule is a little larger

than the tube, so that, when driven in, it compresses the tube very forcibly against the sides of the hole, and makes the joint completely water-tight. The ferrules are sometimes made of wrought iron, but they generally do not last out the tube in that case, and require replacing by new ones before the tubes are worn out: the steel ferrules are better, as they last nearly twice as long. When a tube or a ferrule requires taking out, the ferrule has to be cut quite through with a chisel, and then turned inwards, so as to detach it from the tube, which can then be driven out.

The smaller the tubes are, the greater is the heating surface obtained, as small circles have a much larger circumference in proportion to their area than large ones; but when the tubes are diminished in size, the total area of passage through them from the fire-box to the chimney is also diminished; and consequently if the diameter of the tubes were much diminished, the draught of the fire would be checked from the passage to the chimney being too small. The heating power of the boiler would thus be injured, although the amount of heating surface exposed to the water was increased, and the abstraction of the heat from the hot air rendered more perfect.

Small tubes have another disadvantage in being liable to choke up very much with the particles of coke which are carried through them in great quantities by the force of the draught, and in their retaining the cinders which are continually blown into them, but which pass clear through larger tubes. The small tubes are often contracted one-third in diameter by the deposit of coke on their inner surface during the day's work, and they have to be cleared out every night by passing a rod through them: the larger tubes never require clearing out.

The tubes were at first made of copper, and some have been of wrought iron, but the copper tubes were found to wear very fast, generally lasting only three or four months, and were a great source of expense from the necessity of frequently renewing them. Brass tubes were first tried in the locomotives

on the Liverpool and Manchester Railway in 1833, at the suggestion of Mr. Dixon, the resident engineer, and were found to be very much superior. Brass tubes, of the dimensions mentioned above, last about two years, being six or eight times as long as copper tubes of the same dimensions. This increase of durability appears partly caused by their greater hardness, as it has been observed that the soldered joint, which is made with harder brass, wears less than the other parts; but the whole canse has not yet been satisfactorily ascertained. The tubes are much worn by the friction of the cinders that are blown through them by the force of the draught; but it is very probable that their wear is principally caused by chemical or thermo-electric action. The tubes in the middle and about the fourth row from the bottom are worn out the first, and it is only the ends next the fire-box that are destroyed.

When the tubes become very thin they are crushed inwards by the force of the steam, and the water is blown out at the ends of the tube into the fire; when the tubes are getting old, this frequently takes place whilst an engine is running, and it is stopped by the accident. A plug of hard wood is driven into each end of the burst tube, which is preserved from being burnt by the contact of the water inside the tube, and the engine runs on again. When several of the tubes have burst and been plugged up, they are taken out and replaced by new ones; and if the engine is required to be in constant use, a complete set of new tubes is soon required to avoid the liability of delays from the bursting of the tubes: they weigh about 16 lbs. when new, and lose about 6½ lbs. in the time they are in use. The cost of the brass and of the copper tubes makes the expense of repairing an engine very considerable when a complete set of new tubes is required. The tubes being firmly fixed into both ends of the boiler, it serves to support and strengthen them; but for an additional support to the upper part, six wrought iron rods are placed above the internal fire-box, by the side of each other, and longitudinally in the boiler; and the ends are attached by a pin to a piece of wrought iron (T

iron) riveted on to the end plate of the boiler and to the back plate of the fire-box.

THE SMOKE-BOX is 4 feet wide, like the fire-box, and 2 feet long, and is closed on all sides; the back of it is formed by a wrought iron plate, half an inch thick, closing the end of the boiler to which it is attached by means of a piece of angle iron riveted to both, like the similar joint at the fire-box. The rest of the smoke-box is made of quarter-inch iron plate, the front and back plates being bent in round the edge, and the other plates riveted to them, as in the fire-box, except the front plate, which is fixed by screw-bolts and nuts, because it is required occasionally to take it off.

Upon the smoke-box is fixed the chimney; it is 15 inches in diameter, and is made of one-eighth-inch iron plates, riveted together and bound round by hoops; the top is made funnel-shaped to give more free egress to the hot air, and the bottom has a piece of plate riveted to it, forming a flanch all round, by means of which the chimney is bolted down upon the smoke-box.

In the lower part of the smoke-box are fixed the two cylinders, where the steam is used and motion produced: these will be described afterwards.

The tubes open into the upper part of the smoke-box, and the hot air passes from them up the chimney; no smoke is produced, except at first lighting the fire, as the fuel used is coke, which does not cause any smoke in burning, but only a light dust. The height of the chimney being limited, the draught produced by it is not sufficient to urge the fire to the intense degree of ignition that is necessary to produce steam at the pressure and in the quantity that is required, and some other more powerful means have therefore to be adopted to produce the draught. This is done by making the waste steam issue through the pipe called the blast-pipe, which is directed up into the centre of the chimney, and is gradually contracted throughout its length to make the steam

rush out with more force: this pipe is made of copper one-eighth of an inch thick, and is $3\frac{3}{4}$ inches in diameter inside at the bottom, where it joins on to the cylinders, and tapers to $2\frac{1}{2}$ inches at the top.

The waste steam rushes out of the pipe with great force up the chimney, carrying the air with it, and causing a very powerful draught through the tubes and the fire; a whole cylinder full of steam is let out at each stroke, and the two cylinders deliver their waste steam alternately, so that when the engine is running fast an almost constant current of steam in the chimney is produced, and the interval between the blasts can scarcely be perceived. By this method the fire is not blown, as is usual, by forcing air into it, but by extracting the air from the flues and drawing air through the fire.

There is, however, a considerable loss of power attending the use of the blast-pipe, from the obstruction it causes to the egress of the waste steam; for the waste steam opposes the action of the steam in the cylinders, and should be allowed to escape freely, that its pressure may be as small as possible. This causes the greater economy of working in the large stationary and marine engines, where the waste steam is condensed, and its opposing pressure is reduced almost to nothing; but in a locomotive engine, on the contrary, its average resistance is not less than 6 lbs. on the square inch; and when running very fast, and the issue of waste steam is almost continuous, the whole loss of power amounts to nearly half that of the engine. But the draught must be obtained by an expenditure of some of the power of the engine, whatever means may be employed to produce it; and the plan of producing it by the blast of waste steam is the best, as no power is wasted upon working any machinery for the purpose, and it has the advantage of great simplicity in its application.

The force of the draught produced by the steam blast is so great that cinders are drawn through the tubes, and even

thrown red-hot out of the top of the chimney; sparks are also emitted occasionally, and have sometimes caused accidents. To prevent the cinders and sparks from getting out of the chimney, a wire sieve is often fixed on the top of the chimney, but this has a disadvantage in impeding the draught and the exit of the waste steam very considerably; though it is made convex and larger than the chimney, so as to have a larger surface, and to impede the passage as little as possible. The sieve is, however, but an imperfect remedy, for the cinders are thrown against the sieve with so much force that the meshes are soon destroyed. A sieve has been tried, placed at the bottom of the chimney, so that the blast-pipe ran through it, and in this position it afforded much less obstruction to the draught than when placed at the top of the chimney; for the blast of steam which produces the draught being entirely above it, would not be impeded, and the loss of power from impeding the exit of the waste steam would also be avoided. But the plan was afterwards abandoned, as the sieve was found to be destroyed so quickly as to require constant repair from being exposed immediately to the air, and to all the cinders that are drawn through the holes striking against the front plate of the smoke-box, and rebounding upwards towards the chimney.

Damper.—A damper is placed in the chimney just below the top of the blast-pipe, consisting of a thin iron plate fitting the chimney closely, with a hole cut in its centre, just large enough to allow the blast-pipe to pass through. A flat bar is bolted on to it, to serve as a spindle, and fixed a little out of the centre, in order to clear the blast-pipe when the damper is elevated. This spindle is made round at each end, and turns in bosses riveted to the outside of the chimney; one end passes quite through, and has a short lever fixed on to it: the diameter of this end of the spindle is of the same size as the width of the flat part, to allow of the spindle being put into its place through the hole in the boss in which it turns, before it is attached to the damper in the

chimney. A long rod is attached to the lever on the spindle, and reaches to the top of the fire-box, terminating in a handle, and resting in an iron fork fixed in the top of the fire-box, in which either of two nôtches made in the rod can catch; so as to hold the damper either vertical or in a horizontal position, closing up the chimney.

The damper is used to check the draught when a less intense action of the fire is required, such as when the engine is standing still or running down hill, and very little power is wanted; it causes very little obstruction to the exit of the waste steam, as the blast-pipe passes through it. It is a curious circumstance, that whilst the damper is raised the waste steam passes out of the chimney in an invisible state, unless the atmosphere is nearly saturated with moisture, from the increased capacity of the hot air for moisture enabling it to absorb the steam in the chimney. A slight change in the dryness of the atmosphere or the temperature of the engine fire, causes the steam to be visible; and hence it is always visible in winter, and in summer is invisible only when the hygrometer is high; its appearance is, indeed, a tolerably correct indication of the hygrometric state of the atmosphere. When the damper is lowered, the steam instantly becomes visible from the want of hot air to absorb it, and it then issues from the chimney in dense white volumes.

SMOKE-BOX DOORS.—A large door is made in the front plate of the smoke-box for the purpose of affording access to the cylinders and the tubes; there is a ledge fixed inside round the opening, against which the door is closely pressed by four finger-nuts put upon screws fixed in the smoke-box plate, and passing through projecting lugs upon the door. There is also a small door, near the bottom of the smoke-box, for the purpose of clearing out the cinders and ashes that collect in it: both doors have to fit closely, that no air may enter at them to impair the draught.

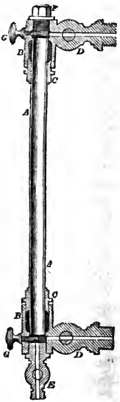
FEED-PUMPS.—The boiler is supplied with water by two feed-pumps, which are worked by the engine: their construc-

tion will be explained afterwards. One of them is sufficient to supply the necessary quantity of water for the boiler, and the other is thrown out of action; but two are furnished in the engine, in order that if one should fail from any accident, the other may take its place without any delay being caused. On forcing the water into the boiler, it checks the generation of steam by its coldness, and the effect of the engine is also diminished in consequence of the power required to work the pump. For this reason, the action of the feed-pump is generally suspended when the engine is ascending an inclination, and requires its greatest power, and the supply of water is made up by working both pumps on a succeeding level or descent: this is an additional advantage in having duplicate pumps. A small cock, called the pet-cock, is fixed in the pipe leading to the boiler from each pump, and a long handle is fixed to it, extending to within reach of the engine-man standing behind the engine. These cocks are opened occasionally to ascertain whether the pumps are working properly, when a stream of water should be forced out at each stroke.

Gauges.—A glass gauge is provided for showing the height of the water in the boiler; it is shown detached in fig. 6, which is a section through the centre of it, to a scale of $2\frac{1}{4}$ inches to a foot, or three times the size of the engraving. The gauge consists of a strong glass tube, A, fig. 6, about three-quarters of an inch diameter outside, fitted into a brass socket, B B, at top and bottom, the joints being made steam-tight by hemp packing put round the glass, and compressed against it by the glands, C C, which are screwed in round the glass. From each of the socket-pieces, B, a tube, D, proceeds, with a cock in it, and a screw on the end for fixing it into the fire-box; and the piece E, containing another cock, is screwed into the lower piece, and the plug F into the upper piece, affording the means of putting the glass tube down into its place. When the two cocks, D D, are opened, the water of the boiler rises in the glass tube to the same height

that it is in the boiler, the upper part of the glass being filled with steam, the height of the water in it showing always the level of the water in the boiler: the cocks are for the purpose of stopping the communication when required, from the gauge being out of order, or otherwise. The cock in the piece D is for the purpose of clearing out the gauge, by allowing a stream of water to run through it; and it is often necessary to open it when examining the gauge, in order to get rid of the bubbles of steam formed by the rapid ebullition of the water, which sometimes render it difficult to ascertain the precise height of the water. The difficulty is also increased by the motion of the engine producing oscillation in the water; but the disturbing effect is much diminished by choking the tube, or making the communication with the boiler through the tube D very small, so as to impede the motion of the water in the tubes. A small plug, G, is screwed in opposite each tube D, to afford the means of clearing out the tubes D, by passing a wire through them when the plugs G are taken out.

Fig. 6.



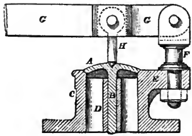
To afford an additional means of ascertaining the height of the water in the boiler, two gauge-cocks are fixed in the side of the fire-box, one being 4 inches above the other, and the lower one 1 inch above the top of the internal fire-box. The boiler is generally filled at starting, until the water runs out at the upper cock; and during working the water level is kept between the two cocks, and often up to the upper one. The cocks are opened occasionally to try the level; and if steam

should ever be found to blow out at the lower cock, showing that there is not more than 1 inch of water over the roof of the internal fire-box, instant attention has to be paid to the feed-pumps, and the fire damped, if necessary, to prevent the roof of the fire-box being uncovered and getting burnt. The glass tube is, however, the more certain guide, being less affected by the oscillations of the water than the gauge-cocks.

THE LEAD PLUG, described before, is an additional security against any accident arising from the water being suffered to get too low in the boiler.

SAFETY-VALVES.—The pressure of steam in the boiler is regulated by the safety-valve, the construction of which is shown in figs. 7 and 8, drawn to a scale of $2\frac{1}{4}$ inches to a foot.

Fig. 7.



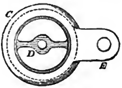


Fig. 8.

Fig. 7 is a longitudinal section through the valve, and fig. 8 a plan of the valve-seat with the valve removed. The valve A is made of brass: it is conical round the edge, or mitred at an angle of 45°, and has a spindle or stalk, B, cast on it in the middle. The seat C of the valve is also of brass, and is cast with a flange at the bottom, to bolt it on to the boiler; and

the valve is ground into the upper part, so as to fit it steam-tight. The opening in the valve-seat, C, is $2\frac{1}{2}$ inches diameter, and across it is cast a thin piece, D, extending to the bottom, and having a longitudinal hole through it, in which the spindle B of the valve works: this is to hold the valve steady when it is raised, and to guide it into its seat again. A projecting lug, E, is cast on the valve-seat, in which is fixed the standard, F; this is forked at the top, and receives the end of the lever, G, which turns in it upon a centre pin; a rod, H, is jointed to the lever by another pin, at 3 inches from the former one, and bears directly upon the valve.

At the other end of the lever, and at a length of 3 feet from the fulcrum, is attached by a finger-nut the rod of a common spring balance, the bottom of which is fixed on to the fire-box: this spring balance is screwed up by the finger-nut on the valve lever, until the required pressure on the valve is produced, which is generally 50 ℔s. on the square inch above the atmosphere; and the valve, on rising to let out the surplus steam, has to raise the spring balance, which acts upon it with twelve times the leverage.

In stationary engines, the safety-valve is kept down by a weight hanging on the lever, and shifted to different positions, to alter the pressure on the valve; but in a locomotive engine a weight could not be used, because the motion of the engine would cause it to jolt up and down, and the valve would be continually letting off steam. There is one disadvantage attending the use of the spring balance that the other plan is free from; namely, that any opening of the valve by raising the lever, compresses the spring in the balance more, and increases the pressure upon the valve, so that the free egress of the surplus steam is checked, and the pressure of the steam is allowed to become greater than that indicated by the balance when the valve is shut: the longer the lever is, the greater is this difference of pressure, and it is sometimes as much as 10 ℔s. per square inch.

In observing the pressure on the safety-valve, allowance

must also be made for the effect of the mitre, or conical part of the valve; for when it is raised, the steam acts on the conical part as well as on the bottom of the valve, and has therefore a greater power in lifting the valve; and this diminution of the pressure on the valve varies with the extent of the mitre and with the degree that the valve is opened.

These different circumstances render the safety-valve but an imperfect means of ascertaining the pressure of the steam in the boiler. In stationary engines, which are generally worked at a much lower pressure, a mercurial gauge is often used to indicate the pressure of the steam; but this instrument cannot be used in a locomotive, as a tube of great size, and not less than 12 feet high, would be required: it has, however, been used as a means of testing the accuracy of the indications of the safety-valve by a temporary connection with the engine.

A lock-up safety-valve is enclosed in a case, to prevent access to it so as to increase the pressure to a dangerous degree. The valve is exactly similar in construction to the other safety-valve, but instead of being held down by a lever and spring balance, several small elliptical springs, about 6 inches long, are placed one above another and over the valve, and pressed down by a screw at the top in the frame, fixed into the valve-seat. By turning this screw, the pressure on the valve can be adjusted to any required degree; and when the case is fixed on, the valve is effectually protected from having the pressure altered. The lock-up valve is loaded rather more heavily than the ordinary working pressure, 50 lbs.; so that it does not blow except when the pressure has exceeded that limit, as in performing work requiring more power than usual.

A large spiral spring is used in some engines to press upon the valve, being fixed in a similar manner to the elliptical springs; it is rather more compact, but is not quite so free in its action, as the pressure increases more rapidly on the using of the valve.

MAN-HOLE.—A circular opening into the boiler is provided,

called the man-hole; it is 16 inches in diameter, and surrounded by a ring, bolted on to the boiler, having a flanch at the top for fixing on the cover. This opening is large enough for a man to enter, and affords access to the interior of the boiler for making repairs in it, or for cleaning it out.

MUD-HOLES.—These are two small openings in both sides of the fire-box at the bottom, closed by plates bolted upon the outside, and are for the purpose of cleaning out the fire-box and removing the sediment that is deposited from the water. Two mud-holes, at opposite corners of the fire-box, are usually opened twice a week, and the deposit washed out by directing a stream of water into them; each pair of opposite holes being opened alternately. The boiler does not often require cleaning, but it is occasionally washed out by putting the water hose in at the man-hole, and washing all the sediment into the fire-box; this is found to be quite sufficient to keep it clean.

BLOW-OFF COCKS.—Two cocks, 1 inch in diameter, are fixed one in each side of the fire-box, close to the bottom, for the purpose of emptying the boiler; this is called *blowing off*, as it is done just after the engine has left work, and the water is blown out with great force by the pressure of the steam. This blowing off serves to cleanse the boiler, and the whole water has to be thus emptied out two or three times a week when the engine is in full work, as it gets foul after remaining in the boiler for some time.

FIRE AND HEATING POWER.—The fuel used is coke, and is that most generally used in locomotives: coal was employed in the first ones, and is now made use of on railways in the collieries and where passengers are not carried; but on the large public railways it is inadmissible on account of the smoke that is produced.* Coke has an advantage over coal in being very light in substance and not caking together, but allowing

* By later improvements in the construction and arrangement of the fire-boxes, the use of coal, instead of coke, has been rendered practicable; and the objections against it, to a great extent, obviated.

the draught of air to pass freely through the fire; it is also capable of attaining a very intense degree of ignition; but its lightness renders it more liable to be drawn through the tubes by the draught, and the fine dust or ashes, produced by its combustion, is very annoying to outside passengers. The coke used is of the best quality; and the operation of coking the coal is performed only with a view to the abstraction of the volatile parts, as the hydrogen, and the losing as little as possible of the carbon: gas coke, or the remains of the coal used in gas works, is very inferior, being overburnt, and having lost a good deal of its carbon to form the gas, carburetted hydrogen: it also contains a good deal of sulphur, which is very injurious to the metal of the boilers: this causes also the principal objection to the use of coal. The coke used in the locomotives on the London and Birmingham Railway is made upon the works, and is very nearly pure carbon. Welsh stone coal or anthracite has been also tried; it produces no smoke or flame, being almost pure carbon, like coke; but it appears to be not suited to locomotives, from its density and flying into small pieces, so as to form a close mass on the fire-grate, and not allow a sufficiently free passage for the air through the fire.

The fuel is carried in the tender behind the engine and immediately contiguous to the fire-door, so that it can be readily shovelled into the fire when required: it is supplied on an average in quantities of about half a cwt. at intervals of from five to ten minutes. The heating the water in the boiler and getting up the steam takes about an hour and three-quarters on an average, and requires the consumption of about one and a half or two cwt. of coke: in some places the boiler and tender are supplied with hot water by means of a stationary boiler, in order to expedite the getting up of the steam, and also as a means of economy.

The area of the fire-grate is $9\frac{1}{2}$ square feet; it is 18 inches below the bottom of the lowest tubes, and the space for the fire, when quite filled up to the tubes, is 14 cubic feet, and

holds about $2\frac{1}{2}$ cwt. of coke; but the fire-box is not always filled so full as this, and usually contains about $1\frac{1}{2}$ or 2 cwt.

The surface of water exposed to the heat directly radiated from the fire is the whole surface of the internal fire-box, deducting the fire-door and the tubes, and is equal to 50 square feet; and that exposed to the current of hot air, or conducted heat, is the interior surface of the tubes, and is equal to 432 square feet. The surface exposed to radiated heat is considerably more efficacious in generating steam than that exposed to conducted heat only, as the supply of heat is more copious, and the proportion was found to be about three times in an experiment tried by Mr. Stephenson: the experiment was made with an old engine, and the proportion is different in the modern engines.

The area of passage for the heated air from the fire-box to the chimney is the sectional area of all the tubes inside the ferrules; the ferrules are $\frac{3}{8}$ths of an inch less than the outside of the tubes, and are therefore $1\frac{1}{4}$ inch in diameter inside; and the sectional area of them all (124 in number) is 1·06 square feet. The area of the passage through the chimney is rather more, or 1·23 feet.

In the "Rocket" engine the area of passage through the tubes was ·90 square feet, or nearly the same as in this engine, though the fire-grate was but half the size; but the heating surface of the tubes was only one-third, from the large size and small number of the tubes: the heating surface of the fire-box was only three-quarters of that of the present engine.

In the old engines before the "Rocket," the area of passage through the flue was two and a half times the size, but the heating surface was only one-thirteenth of that in the present engine; the fire-box had also only one-fifth of the heating surface; the fire-grate was three-quarters of the size.

THE CYLINDERS, AND THE MANNER OF USING THE STEAM.

Steam-pipe.—A steam-pipe is provided for conveying the steam from the boiler to the cylinder, where it is to be used;

it is made of copper $\frac{3}{16}$ths of an inch thick, and the part within the boiler is 5 inches diameter inside; it passes through the tube plate of the smoke-box and is bolted to it by a flanch. The pipe then divides into two smaller ones, $3\frac{1}{2}$ inches in diameter, which pass down on each side of the smoke-box to the cylinders; they are turned on one side in order to keep them clear of the tubes, so as to allow access to all the tubes, that they may be taken out, when necessary, through the smoke-box door. It is also necessary to protect the steam-pipes from the immediate action of the hot air issuing from the tubes, which is nearly hot enough to melt copper. In the first engines, the steam-pipes were brought straight down to the cylinders across the ends of the tubes, but they were found to be very rapidly destroyed.

The area of the large steam-pipe is 19·6 square inches, and is equal to the areas of both the small ones, which are 9·6 square inches each.

The other end of the steam-pipe is connected to a box by means of a stuffing-box, containing packing made of loose-spun hemp, called gasket, compressed against the steam-pipe by a brass gland, which is bolted to a flanch on the stuffing-box. This stuffing-box is necessary because iron expands by heat only two-thirds as much as copper, so that when the boiler and its contents are heated, the wrought iron increases in length less than the copper pipe, and the pipe would be very much strained if it were rigidly fixed at both ends, and the joint would soon become defective by the repetition of the action; but the stuffing-box allows the end of the pipe to slide through it, and still keeps the joint steam-tight, preventing all injurious action.*

The steam enters through a funnel-shaped copper pipe which is fixed upon the top of the box, and this pipe rises nearly to the top of the steam dome, which is made of brass,

* The brass tubes of the boiler are liable to the same action; but as they are small and very firmly fixed at the ends, the expansion is immaterial, the tubes allowing for it by bending slightly.

cast ⅝ths of an inch thick, and is 15 inches in diameter and 2 feet high, and bolted down by a flanch on to the fire-box. The object of this steam dome, and of carrying the steam-pipe up to the top of it, is to obtain the steam as pure and dry as possible, by taking it at a distance from the water; because from the great agitation of the water in the boiler, and the rapid emission of the steam to the cylinders, some of the water gets mixed up with the steam in a finely divided state, and is liable to pass over with the steam into the cylinders. This effect is called *priming*, and is very injurious when it takes place to any extent, for all the water carried over into the cylinder is wasted, and occupies the place of steam, and thus diminishes the power of the engine; but principally because it accumulates in the cylinder and sometimes remains in it, being unable to escape with the waste steam; and in that case, from being so incompressible, it causes the breaking of some part of the engine. By carrying the steam-pipe up into the dome, the quantity of water taken with the steam is very much diminished, as it has time to separate, and the expanded end of the steam-pipe, nearly filling the dome, serves to catch the water and prevent its entering the steam-pipe.

The priming is much increased when the water in the boiler is not clean or pure; and an engine that does not prime perceptibly with good water, may prime very much if supplied with impure or hard water. When priming, the water is thrown out in a shower from the chimney at each blast; and the power of the engine is very much impaired, as the violence of the ebullition of the water is thereby greatly increased. The prevention of the priming was found to be a very great difficulty in the first locomotives, and several contrivances were made use of for the purpose,—such as making the steam-pipe pass through a plate pierced with holes before entering the steam-pipe, or dividing the dome by a plate, over which the steam had to pass to the steam-pipe. But it has been observed that the priming has been gradually diminished by increasing the steam room, or space in the boiler occupied only

by steam, for this renders the generating of the steam more uniform, as the abstraction of the successive cylinders full of steam is less felt and causes less agitation when the total quantity of steam is greater. In the first locomotives very little steam room was afforded; but in this engine the steam room is generally about 44 cubic feet, and there is no perceptible priming under ordinary circumstances.

Fig. 9.

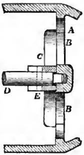
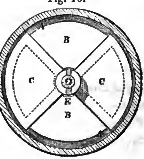


Fig. 10.



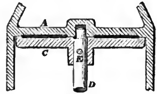


Fig. 11.

REGULATOR.—In the box is placed the regulator, extending across the box, so that all the steam must pass through it before it can enter the steam-pipe; and by means of this the steam is either shut off or allowed to enter the steam-pipe in greater or less quantities. The regulator is shown in figs. 9, 10, and 11, to a scale of $1\frac{1}{2}$ inch to a foot. The box is made of cast iron half an inch thick, and has a plate, A, extending across it, with two openings, B B, of nearly a quadrant each; the diameter of the opening is $8\frac{1}{2}$ inches, and that of the solid part in the centre separating them 2 inches. The brass plate C, placed against this plate, fits exactly the space between the openings B B, and, if turned round and placed over the openings, would project beyond or overlap them $\frac{3}{4}$ of an inch on each side, as they are $\frac{3}{4}$ of an inch smaller than a complete quadrant. The spindle, D, passes through a boss in the centre of the plate C, turning at its end in a socket of the plate A, but without touching the bottom of the socket, and a small pin is fixed into the spindle, fitting into a notch, E, in the centre boss, to enable the spindle to turn

round the regulator plate c, and yet allow it to be withdrawn a little without drawing the regulator plate away from the other plate. The plates are held together by the pressure of the steam; and by forming the connection with the spindle in this manner, they are enabled to keep in close contact, although the position of the spindle should be altered, and the regulator plate is still made to turn with the spindle.

The two plates are ground together, so that when the regulator plate is turned round and covers the openings, the passage is closed completely steam-tight; the under side of the regulator plate, and the solid part between the openings in the other plate, are both hollowed a little in the middle, as shown in the section through the centre of each, in fig. 11, so that they touch only for a space of $\frac{3}{4}$ of an inch round the edge. This diminishes the labour of grinding them, as there is so much less surface to grind, and also insures their fitting round the edges, where alone it is required; for the little steam that will pass through the hollow between the plates, when the regulator is partially open, is of no consequence, as it will only slightly increase the quantity of steam passing through.

The other end of the box is fixed by a flanch to the back plate of the fire-box; and an opening is cut in the plate corresponding to the inside of the box, which is closed by a plate having the stuffing-box fixed on to its inside with its gland. The spindle of the regulator turns steam-tight in this stuffing-box, a collar on the spindle resting against the end of it; and a handle is fixed on the end of the spindle, moving between two brass arcs, which are connected together at the ends, and bolted on to the fire-box: these arcs serve as guides for the handle when moved, and stop it at each side. The regulator, when quite open, if made to turn round, will immediately begin to contract the passage for the steam; and when turned a quarter round, the passage will be completely closed. The motion of the handle is therefore through a quarter of a circle, or half a quadrant on each side of the vertical position. When the handle is put down on the right hand side, the regulator

is shut; and when down on the left side, it is full open; and in intermediate positions the regulator is proportionally open, except for the small distance at each end along which it is passing over the over-lap. The area of passage through the regulator, when full open, is 21·9 square inches, or a little more than the area of the steam-pipe, which is 19·6 square inches.

This is the form of regulator that is most frequently used, as it is simple in its construction, and not liable to get out of order, and particularly as it is very uniform and regular in its action; and, excepting the small overlap, the degree of opening is exactly proportionate to the amount of motion of the handle. Another contrivance that is also used for the purpose, consists of a conical valve like a safety-valve, which closes the end of the steam-pipe, and is drawn away gradually from its seat, when turned round with the handle, by means of a fixed pin fitting in a spiral groove on the spindle, similar to a screw; only that the groove makes but a quarter of a turn round the spindle, and is very much inclined to it, so as to cause the valve to be sufficiently drawn back by a quarter-turn of the handle. This regulator is very efficient, and acts a little more uniformly than the other; but the friction in it is greater, from the spiral motion, and it is more liable than the other to get out of order and stick fast.

STEAM CHESTS.—The steam chests or slide valve-boxes are made of cast iron $\frac{1}{2}$ an inch thick, and are bolted down upon the top of each cylinder, and to the front plate of the smoke-box, in which holes are cut of the same size as the steam chests, and closed by cast iron plates, termed "bonnets," bolted on the outside. The steam chests have the two branches of the steam-pipe fixed upon them at the back, and opening into them; and a stuffing-box is cast upon the end of each, passing through the tube plate, the joints being completely and firmly closed by running melted lead into it all round.

SLIDE-VALVES.—In the steam chests are placed the slide-valves. They are brass boxes $1\frac{1}{2}$ inch deep inside, and $\frac{3}{8}$ of

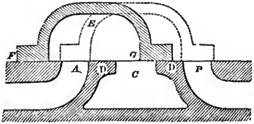
an inch thick, having flanches $\frac{5}{8}$ of an inch thick all round them at the bottom. The slide-valves are made to move backwards and forwards by spindles, which have each a cross piece at the end that fits into a notch in the back of the valve; the spindle is generally connected to the valve by means of a rectangular wrought iron frame called a bridle, dropped over the valve, and having the spindle screwed into it. The bridle has an advantage, in holding the valve very steady, and yet allowing it to drop through readily, as it is worn by friction, and thus keep always in contact with the surface that it slides upon. The valve spindle moves steam-tight through the stuffing-box at the inner end of the steam chest.

Cylinders and Pistons.—The cylinders, where motion is produced by the pressure of the steam, are made of cast iron, $\frac{5}{8}$ of an inch thick and 12 inches diameter inside, and are bored out perfectly smooth and cylindrical. A box is cast on the top flat of each cylinder, running along its whole length, and on the upper side, containing two hollow rectangular passages, and another passage between them; these are separated from each other, and the ends of them are shown coming to the outside, and opening into the steam chest at the left cylinder. The two outer passages are the steam-ports; they are 8 inches long and 1 inch wide, and open one into each extremity of the cylinder, for the purpose of conveying steam to and from the cylinders; their area is 8 square inches, or rather less than the area of the steam-pipes. The other passage is the waste steam-port, of the same length, and $1\frac{1}{2}$ inch wide on the face; expanding inside, occupying all the space between the steam-ports, and passing round the cylinder, until it clears the steam chest and comes to the outside again, opposite to the other cylinder; having gradually assumed a circular form $3\frac{3}{4}$ inches in diameter. The cross area of this passage is made of such dimensions, that, although it alters in shape, it is in all parts equal to the area at the end, that of a circle $3\frac{3}{4}$ inches diameter, or 11 inches area. On the outside of this opening in each cylinder are fixed the two ends of the branching copper pipe,

of the same diameter, termed "a breeches piece," and having the blast-pipe bolted on to it. This piece is fixed on to the cylinders by screws put into holes tapped to receive them in the solid metal, as there is no place for nuts. The steam chest is also fixed on to the cylinder at the hinder end in the same manner. The flanches are made rather thicker, to allow for being weakened by the holes in them, and those of the copper pipes are $\frac{3}{8}$ of an inch thick, and made of brass, soldered on to the pipe: the pipes are made of $\frac{1}{8}$ of an inch sheet copper, lapped and soldered at the edges. A layer of canvas or of gasket, like that used for packing, covered with red lead and oil, is placed between the flanches of the pipes and under the flanch of the steam chest, and in all other similar joints, in order to make them steam-tight.

The face of the ports that the slide-valve moves upon is made quite even and true by a planing machine, and the valve is ground upon the face to make it fit steam-tight; the face is sunk down round the ports beyond that part over which the slide moves, in order to diminish the surface to be planed and ground. The spaces between each of the steam-ports and the waste-port, called the bars, are 1 inch wide. A section of the slide-valve, quarter size, is shown in fig. 12, where A and B

Fig. 12.



are the back and front steam-ports, C is the waste-port, and D D the bars. The width of the slide inside is the same as the ports; the length E (fig. 12) is $\frac{1}{8}$ of an inch less than the distance between the ports, and the flanches F and G are $\frac{1}{8}$ of an

inch wider than the ports: so that when the slide is in a central position, as shown by the dotted lines, the flanches F and G lie exactly over their respective steam-ports, and overlap them $\frac{1}{16}$ of an inch on each side. This overlap is for the purpose of insuring that one port is completely closed before the other is opened, in order that they may never communicate with each other under the slide during its motion, nor the steam be allowed to enter both ports at the same time.

The slide-valve is moved backwards and forwards a distance of 3 inches, or $1\frac{1}{2}$ inch on each side of the central position, and is carried beyond the inner edge of each steam-port alternately, a distance of nearly $\frac{1}{2}$ an inch, as shown in fig. 12, before its motion is changed and it begins to move back again: this distance that the slide moves beyond the port is called "the travel." The waste-port is always covered by the slide, as the travel is less than the width of the bars, so that the steam is always prevented from entering the waste-port from the steam chest. During the reciprocating motion of the slide, each of the steam-ports is alternately uncovered, and the steam allowed to enter and flow into the cylinder. The port is then covered again by the slide, and when the flanch has passed over communicates through the inside of the slide with the waste steam-port, allowing the steam which has performed its duty in the cylinder to escape by the port at which it had entered, into the waste-port, and out at the blast-pipe: this action is called "the eduction." The slide-valve is held upon the face of the ports only by the pressure of the steam upon it, which is quite sufficient to keep it always steam-tight whilst moving, as all the inside of the slide is open to the air through the waste-port, and the flanches fit air-tight upon the face of the ports; so that the whole pressure of the steam upon the slide is effective in keeping it down: the area of the slide being 55 square inches, the pressure upon it is about $1\frac{1}{4}$ ton. In large stationary engines the steam is admitted under the slides, as the pressure of the steam upon the slides would be more than is necessary to keep them tight, and would cause

very great friction: the slides have, in this case, to be held down by other means, as packing or springs upon the back of them. At the extreme position of the slide, as in fig. 12, the inner edge of the flanch G approaches the opposite bar, thus contracting the opening of the waste-port to the size of the port out of which the steam is escaping: if contracted more, the free exit of the steam would be obstructed.

The front end of each of the cylinders is closed by a cast iron cover, $\frac{7}{8}$ of an inch thick, let into it; the cylinder runs through the plate of the smoke-box, projecting beyond it, and having a flanch resting against the inside of the plate, and fixed to it by bolts, which are screwed through the plate into the flanch. The cylinder cover is of the same size as this flanch, and is held on to the cylinder by the same bolts that fix the cylinder to the smoke-box plate: the heads of the bolts are made thin to clear the cover, and the bolts are prolonged beyond their head to pass through the cover, and have nuts screwed upon them on the outside. The other end of the cylinder has also a flanch, by which it is bolted to the inside of the tube plate: this is shown on a large scale in figs. 13 and 14, which are a longitudinal and a cross section of the cylinder to a scale of $2\frac{1}{4}$ inches to a foot. O O is a section of the cylinder; P P, the back steam-port leading into the end of the cylinder; Q Q is the tube plate or back plate of the smoke-box; and R, the flanch upon the cylinder, similar to that at the other end. The cylinder runs through the plate, and comes flush with the outside; the joints and the space between the flanch and the plate are run with lead all round, to make the cylinder quite firm and steady, as the hole in the plate does not accurately fit the cylinder; the joint at the other end of the cylinder is also run flush with lead for the same reason. The flanch is fixed to the plate by six $\frac{3}{4}$ inch bolts, which are screwed into the flanch from the outside, in order that they may fit closely to the holes in the flanch and the plate, and hold the cylinder quite steady. A flanch, S S, is cast on the inside of the end of the cylinder, projecting into

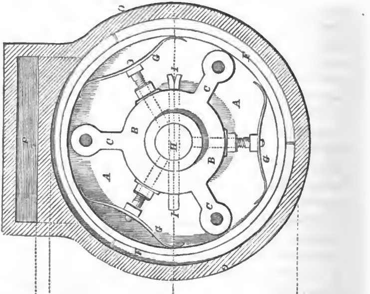


Fig. 14.

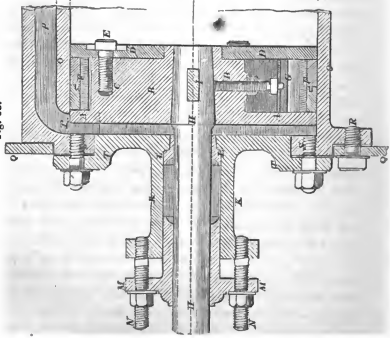


Fig. 13.

the cylinder, and the cover T is bolted to the outside of this flanch, having a projection in the centre that fills up the opening, and makes the end of the cylinder even or flush inside: the cover is fixed on by six bolts, screwed into the flanch of the cylinder, and having nuts on them on the outside; the bolts are made square where they pass through the cover, to prevent their turning when the nuts are screwed on. It is not required to have ready access to this end of the cylinder; but at the other end it is necessary that there should be no obstruction, as the cylinder is required to be completely opened occasionally to get the piston in and out. There is one piston in each cylinder, fitting the cylinders accurately, so as not to let any steam escape between them and the cylinders when they are moved backwards and forwards. The piston is made entirely of brass, and consists of a plate A (figs. 13 and 14), $\frac{5}{8}$ of an inch thick, having a boss, B, cast on the centre, with three arms, C C C, $\frac{3}{4}$ of an inch thick, also cast upon it, radiating from the centre, and equidistant from each other. These arms and the centre boss stand up $2\frac{1}{2}$ inches from the plate A, and another plate D, of the same thickness as the first, is put upon them, making the whole thickness of the piston $3\frac{3}{4}$ inches. The plate D is held steady in its place by a projection on the centre boss passing through it, and is fixed by screws, C C, tapped into the bosses at the ends of the arms C, the heads of the screws C C being countersunk into the plate D. The plates A and D are turned so as to be just capable of moving in the cylinder without touching it, and three brass rings, F F, are placed between them. The inner ring is $\frac{3}{8}$ of an inch thick, and is the same width as the space between the plates: the two outer rings are $\frac{1}{2}$ an inch thick, and of half the width; and one of them has a projecting ring or rebate upon its edge, fitting into a corresponding groove in the other to keep them steady. The rings are turned exactly to fit the cylinder and each other, and cut through in one part, having been first hammered a little all round on the inside, which gives them a tendency to expand, and causes them to fly open on being cut:

when, therefore, they are put in their places in the cylinder, they press against the cylinder by their elasticity, and keep in close contact with it, so as to make a steam-tight joint during the motion of the piston. The divisions in the rings are placed in opposite positions, or break joint, in order to prevent the escape of steam through them; for if they were to coincide, a passage would be left for the steam through the piston.

The elasticity of these rings is found to be quite sufficient to keep the piston steam-tight when moved in the cylinder, and it continues so for a long time; when, however, the rings become so much worn by the friction as to have expanded nearly to the utmost, some other means is necessary to press them against the cylinder. For this purpose the three steel springs, G G G, are placed in the piston; they are of the same width as the inside ring, against which they bear, and one-eighth of an inch thick in the middle, and a pin is put through each of them, having a collar bearing against the spring, and screwed at the other end into the centre boss of the piston; by unscrewing the pin a little, the spring can be made to press harder against the ring when required, and the pin is then fixed by screwing up the set-nut upon it against the boss. When the piston is first made, and the rings are new, these springs are not required, and they are set so as only to touch the rings; but as the rings wear, and become too loose in the cylinder, the springs are screwed up more and more, and made to press harder against the rings; and when they are very much worn, they are kept tight to the cylinder by the springs only, as they have expanded to their utmost. Access is readily obtained, when necessary, to the inside of the piston, by taking off the front cylinder cover and unscrewing the front plate, D, of the piston.

The pistons are often made upon different modifications of Barton's principle, with two or more rings of cast iron or brass, about 1 inch thick, cut into three or four segments, and having wedges inserted between them, which are con-

stantly pressed outwards by springs, so as to keep the segments always tight to the cylinder. The springs are either spiral or flat springs, like those in the engraving; or a circular steel hoop, a little larger than a circle touching the ends of the wedges, is forced in so as to bear against them. These pistons are liable to a defect from which the other with the spring rings is free—that of wearing grooves in the cylinder where the points of the wedges rub against it, as the wedges have to wear down faster than the segments. The plan shown in the engravings is very efficient, and appears on the whole to be the best. The hemp packing used sometimes in stationary engines is now generally superseded by metallic packing, as it requires frequent renewal and is unequal in its pressure, the piston having to be packed very tight at first in order to keep so for any considerable time; in a locomotive, where the motion of the piston is very rapid, it would be quite inadmissible.

The piston-rod is $1\frac{3}{4}$ inch diameter, and is made conical at the end, being increased to $2\frac{1}{8}$ inches diameter in the centre boss of the piston, which is fitted upon it very exactly, and fixed by a cotter or key $\frac{1}{2}$ inch thick, and tapered slightly from $1\frac{1}{2}$ inch wide; the piston-rod has to be fixed very firmly, and is split at the end to prevent its getting loose. The other end of the piston-rod passes through the stuffing-box, K (figs. 13 and 14), in the cylinder cover; it is made of steel, and turned truly cylindrical, to move through the stuffing-box with as little friction as possible. The stuffing-box has $\frac{1}{2}$ inch space round the piston-rod for the packing, which rests against the brass ring or bush, L, fitted on to a small flanch at the end of the stuffing-box, and is compressed by the brass gland, M, which leaves about 3 inches for the packing. The gland has two projections on the outer end, making an oval shape, and is held by bolts passing through these projections, and screwed into corresponding projections on the stuffing-box.

The piston is impelled by moving the slide-valve from its central position, so as to admit the steam from the steam-

chest into the cylinder through one of the ports, and the steam pressing against the front of the piston impels it to the back end of the cylinder. The slide is then moved to the opposite position, covering over the front port and opening the back port, to admit the steam behind the piston and impel it back again to the fore end of the cyliuder; at the same time allowing the steam in front of the piston, which had impelled it before to the back of the cylinder, and is now waste steam, to escape by the inside of the slide and the waste-port into the blast-pipe, rushing out thence up the chimney. At the end of this *fore stroke* the position of the slide-valve is again reversed, to admit the steam in front of the piston and impel it to the back of the cylinder, or make the *back stroke;* the waste steam behind the piston escaping through the back port and the inside of the slide into the waste-ports as before; and on repeating the forward motion of the slide, another fore stroke is produced. The steam is thus made to produce a reciprocating motion of the piston from one end of the cylinder to the other—by moving the slide backwards and forwards from one extreme position, when one port is opened to the steam—to the other extreme, when that port is closed and the other opened. The motion of the slide is in the same direction as that of the piston, but precedes it, as it must take place before the stroke of the piston; and it is produced by the machinery, as will be explained afterwards. The amount of motion, or *length of stroke* of the piston, is 18 inches, and it moves to within $\frac{1}{2}$ inch of each of the cylinder covers. In stationary engines, the action of the steam in the cylinder is exactly similar; but the cylinders are vertical instead of horizontal, and the strokes of the piston are up and down instead of fore and back. The horizontal position of the cylinders is disadvantageous in causing an unequal wear of the pistons and cylinders, from the weight of the pistons and piston-rods acting always on one side, and in also producing a strain on the piston-rod from the wearing of the piston. However in locomotives,

where the pistons are very small and light, this unequal wear is quite imperceptible, though in large stationary engines, whose pistons are several feet in diameter, the action would be very injurious; and many small stationary engines are also made with horizontal cylinders, as the arrangement has several advantages in simplifying and strengthening the machinery.

When the waste steam is let out at the end of each stroke, there is also let out the steam occupying the space of ½ inch at the end of the cylinder beyond the stroke of the piston, and the quantity required to fill the ports, which are both lost, as they are expended without producing any effect. The steam lost at the ends of the cylinder cannot be avoided, as some clearance must be allowed for the piston, to prevent the chance of its striking against the cylinder covers, and also to allow space for the escape of water that may accumulate in the cylinder, either from priming or from condensation of steam. To let out this accumulated water, a cock fixed in a boss in the centre of each cylinder cover is opened occasionally. A small pipe with a cock in it is also fixed into the lower part of the blast-pipe, passing through the bottom of the smoke-box for the purpose of letting out any water that may accumulate there. The steam lost in the ports can be diminished by shortening them, and for this purpose double slide-valves have been used; the ports were carried directly up from the cylinder at each end, a branch from the waste-port being brought up alongside of them, corresponding in size and distance with the present one, and a separate slide placed over each port. The action of the steam in this arrangement was exactly the same as in the present one, but the quantity of steam wasted in the ports was much diminished. Double slides were used in several of the first locomotives, but they have since been abandoned, as the quantity of steam contained in the ports is but small compared with the contents of the cylinder, and the arrangement added considerably to the friction and the complexity of the machine. However, in all stationary engines, except some

of the smallest, double slides are used, but they are generally of a different construction, and made together in one piece.

CROSS-HEADS AND GUIDES.—The outer end of the piston-rod Y is attached to the cross-head, shown on a large scale in figs. 15, 16, and 17, which are drawn to a scale of $2\frac{1}{4}$ inches to a foot. Fig. 15 is a plan, one side being shown broken off, as it is exactly like the other side; fig. 16 is a longitudinal section through the centre; and fig. 17 a cross section shown complete on both sides. The end of the piston-rod A A is turned down smaller, and fitted into the wrought iron socket B B by the key or cotter and gibs C and D; the gib D being tapered like the key, making their outer edges parallel. Two arms, E E, project from the end of the socket B, parallel to each other, having a semicircular notch at the end, fitted exactly to the cross-head F, which is a turned iron pin, $1\frac{3}{4}$ inch in diameter. The cross-head F is attached to the arms E E, of the socket B B, by wrought iron straps, G G, fitted on to both, and fixed by the keys and gibs H and I; the gibs being required to prevent the ends of the straps being sprung open by driving the keys. A small projection upon the cross-head is fitted into a notch in one of the arms D, in order to prevent its turning round.

The ends of the cross-head K K are inserted into two guide-blocks L L, 6 inches long and $1\frac{3}{4}$ inch thick, with flanches on the inner side; these are made of steel and are grooved on the sides, to save metal. Each of these guide-blocks is placed between two steel bars, M N, $2\frac{1}{2}$ inches wide, fixed firmly to the frame of the engine. The guide-blocks and bars are ground together and fitted accurately, enabling the blocks to slide steadily and easily between the bars; the upper bar, M, is $\frac{5}{8}$ inch thick, and the lower one, N, 1 inch thick in the middle, and $\frac{5}{8}$ inch at the ends, the two being connected firmly together by small pillars fixed into them at each end. The lower bar, N, is required to be stronger than the upper one, as it is only supported at the ends. The upper bar, M, is fixed to a piece of angle iron, O (fig. 17),

Fig. 15.

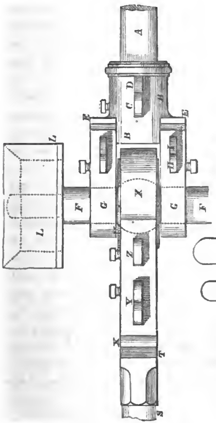


Fig. 16.

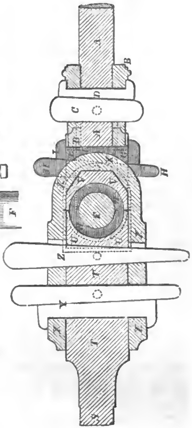
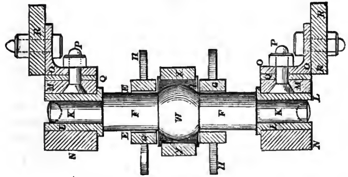


Fig. 17.



by bolts P, with countersunk heads, ground down flush with the bar; small pieces of brass, Q, being interposed between the bar and the angle iron at each of the bolts, affording the means of adjusting the bars accurately level when the angle iron O is fixed on to the engine framing R. The bars M N are adjusted exactly parallel to each other and to the axis of the cylinder, so as to allow the blocks, L, to slide behind them without any strain when moved by the piston-rod and cross-head; and they serve the purpose of guiding the end of the piston-rod, and causing it to move always exactly in the line of the axis of the cylinder.

Connecting-rods.—The connecting-rods are fixed at one end to the cross-heads, and at the other end to cranks on the axle of the large wheels of the engine; they are of wrought iron, 2 inches diameter in the middle, and taper down to $1\frac{5}{8}$ inch towards the ends. The manner of fixing them to the cross-heads is shown in figs. 15, 16, and 17, S being the end of the connecting-rod, enlarged at T T to 3 inches wide, and made square and flat at the end. The brass bearing, U, is fitted to the end, and has another brass piece, V, upon it, made octagonal on the back; the two brasses are 2 inches wide, and have flanches upon them at the sides, as shown by the dotted lines in fig. 16, that of the end brass, V, being semicircular.

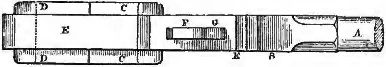
The brasses are fitted accurately on to a spherical ball, W, that is turned upon the middle of the cross-head, and are held upon the end of the connecting-rod, T, by the iron strap, X, fitted between the flanches of the brasses and fixed to the connecting-rod by the key and gib, Y, so as to hold them steadily and firmly together. The key Z is put through the connecting-rod and strap close to the inner brass, U; the holes in the strap being made larger than the key at the outer end, so that the key bears against the brass U, and forces it against the brass on the cross-head. The connecting-rod moves upon the cross-head, and the friction causes the brasses to wear, so that they require tightening up occasionally by

driving in the key z further, and bringing them nearer together: a little space is left between the brasses to allow for this. Small screws are inserted opposite to each of the keys, and are screwed against them when they are driven into their places, to prevent their jolting loose.

The construction of the other end of the connecting-rod is shown on the same scale in figs. 18 and 19, which are a plan and a longitudinal section of it.

A is the end of the connecting-rod, which is enlarged at B B

Fig. 18.



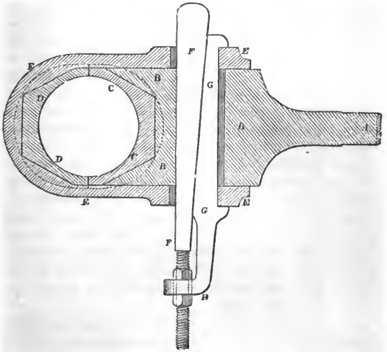
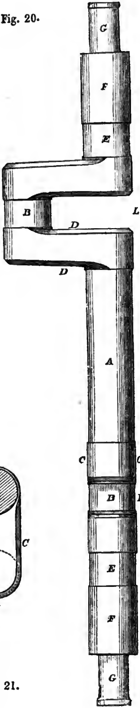


Fig. 19.

to $5\frac{3}{4}$ inches wide, and cut out to an octagonal shape at the end, fitting the brass bearing C. The other brass, D, is similar to it, and they are both 3 inches wide, with semicircular flanches on the outside to hold them steady, and are fitted on to the crank-pin, which is cylindrical and 5 inches in diameter, as shown by the dotted lines in fig. 18, and rounded out to a shoulder on each side. The brasses are held by the strap E, which is fixed on to the end of the connecting-rod by the key F and gib G; the key terminates at the bottom in a screw passing through the prolonged end, H, of the gib, and held by nuts. These nuts are screwed up against the end of the gib, when the key is driven into its place, and effectually prevent its jolting loose; the hole for the screw being made oblong, to allow for the side motion of the key. The holes in the strap E, for the key, are made rather longer outwards than the key, and the key-way in the connecting-rod is as much longer at the inner end, causing the key to bear only against the connecting-rod, and the gib against the strap; the strap is thus drawn further on the connecting-rod by driving the key, and the brasses are brought nearer together and tightened up on the crank-pin, as they are worn by friction. This end of the connecting-rod is shortened as much as the brasses wear, as the outer brass is drawn inwards by the key; but the other end of the connecting-rod is lengthened by the wear of the brasses, because the outer brass is fixed and the inner one is pressed against it by the key. The total length of the connecting-rod is thus kept always nearly the same, as the wear of one set of brasses compensates for that of the other. If this were not the case, the piston would be brought nearer to one end of the cylinder than the other by the wear of the brasses, and would require more clearance to prevent its striking the cylinder cover.

Cranked Axle.—The axle of the large wheels is called the cranked axle, from its having two cranks in it, to which the connecting-rods from the two pistons are attached. It

Fig. 20.



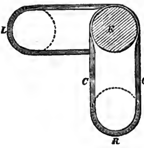


Fig. 21.

is drawn to a scale of 1 inch to a foot, in figs. 20 and 21. It is made all in one piece, and of the best wrought-iron, termed "back-barrow," or scrap-iron, and is $6\frac{1}{2}$ feet long and 5 inches in diameter. The axle is cylindrical at the centre part A (fig. 20), and is increased to $5\frac{1}{4}$ inches at C C, where the cranks are formed. The two cranks R and L, for the right and left hand cylinders, are exactly at right angles to each other, as shown in fig. 21, which is a section through the axle at E; the sides of the cranks, D D, are 4 inches thick. The crank-pins, B B, are 5 inches diameter and 3 inches long, the same dimensions as the brasses in the ends of the connecting-rods, which are fixed upon them; and the length of the cranks from the centre of the axle to the centre of the crank-pin is 9 inches, which is exactly half of the stroke of the piston. Upon the parts F F, which are $7\frac{1}{2}$ inches long, the wheels are firmly fixed, so as to prevent their turning or shaking upon the axle; and outside the wheels, at G G, the axle is reduced to $3\frac{1}{8}$ inches diameter for 5 inches in length, having a collar at the end: these parts, G G, turn in brasses, which are fixed in the outside frame of the engine, and have the weight of the engine resting upon them. The axle is all turned in a lathe, and each of the crank-pins is also turned by suspending the axle on centres corresponding with the centre of the crank-pins, and made in strong cast-iron arms that are firmly fixed on the ends of the axle, and project beyond the cranks so as to balance the axle, and enable it to turn round on the centre line of the crank-pin. The axle is by this means made very true, and the cranks are made of exactly the proper length, and at right angles to each other. The corners of the cranks are chamfered off, as shown in the figure, and the ends of the smaller cylindrical parts well rounded out.

If, when the piston in the cylinder is in the middle of its stroke, or at half stroke, the piston be made to move backwards by admitting the steam to the front of it, it will press against the crank-pin by means of the piston-rod and con-

necting-rod, with a force equal to the pressure of the steam upon it; and as the piston is 12 inches diameter, or 113 square inches area, this force upon the crank will be $2\frac{1}{2}$ tons when the steam is at the usual pressure of 50 lbs. per square inch. And as the cylinder and cranked axle are firmly connected together by the frame-work of the engine, they cannot be separated by this force upon the crank; the crank therefore gives way by turning round, making the axle and wheels upon it revolve until it is brought to its furthest position and becomes horizontal, and the piston has arrived at the end of its stroke.

On reversing the slide-valve to admit the steam behind the piston, and produce a fore stroke, the piston has no power to move the crank, as it is pulling directly in a line with the centre of the axle, and only tending to break the axle; and the crank has therefore to be moved on, so as to rise a little above the centre line, when the piston is able to move it, and pulls it round to the opposite position, or the side next the cylinder, and the piston arrives at the end of its stroke. On the commencement of a back stroke the piston has also no power to move the crank, it being again on the centre, and requiring to be assisted on a little to enable the piston to act npon it and push it round to the opposite side again. The crank requires assisting over these two centres, or dead points, in order that continued rotation may be produced by the reciprocation of the piston; and for this purpose the two cranks upon the axle, which are worked by the two pistons, are placed at right angles to each other; for when one of the cranks is on the centre, and the piston connected with it has no power to make it revolve, the other is at half stroke, and its piston has the greatest power upon it, so that it moves the axle round and makes the other crank pass the centre. In a similar manner, when they have made a quarter-revolution, the right hand crank comes to the centre, but the piston of the left crank is then in full action, and this continues throughout the revolution, one crank being

always in full action when the other comes to the centre and ceases to propel the axle.

The power of the piston to propel the crank is greatest at half stroke, when the connecting-rod is at right angles to the crank, and acts with the leverage of the full length of the crank; but as the piston advances to the end of the stroke, the angle that the connecting-rod forms with the crank is continually diminishing, and with it the leverage and power to propel the crank, until at the end of the stroke the crank comes to the centre, and the connecting-rod ceases to have any power to move it, the mean leverage throughout the stroke being only about two-thirds of the length of the crank. This would cause the motion, therefore, to be very irregular if there were only one crank; but with two cranks placed at right angles to each other, the irregularity is very nearly corrected; as at half stroke the power of one piston only is effective, and at quarter stroke the power of both pistons together, though acting with equal advantage, very little exceeds the full power of the one alone. In stationary engines which have only one cylinder, the irregularity of the action of the crank is compensated for by the use of a large and heavy fly-wheel, which, when once set moving, has sufficient momentum to bring the crank over the centre, and to render the velocity of the motion nearly uniform, as there is not time to accelerate its velocity perceptibly in the middle of the stroke, or to diminish it at the ends. Marine engines which have no fly-wheels are always in pairs, like locomotives, except in some of the smallest vessels.

The connecting-rod being inclined below the piston-rod during the back stroke, and above it in the fore stroke, requires a moving joint at the end which takes hold of the cross-head; and the cross-head is made spherical at that part, to prevent any lateral strain that might arise during the motion from the crank not being accurately in the line of the piston-rod, or the axle at right angles to it. The varying position of the connecting-rod also renders the guides

for the piston-rod necessary to resist the great oblique strain upon it caused by the inclined positions of the connecting-rod tending to force it upwards in the back stroke, and in the opposite direction during the fore stroke. This oblique strain is diminished by increasing the length of the connecting-rod, which is therefore made as long as possible, in order to diminish the friction of the guide-blocks, leaving only a small clearance beyond the crank and head of the piston-rod at their extreme positions. Other modifications of the plan are also used to preserve the parallel motion of the piston-rod, such as a single square bar placed on each side with the edges at top, termed "diamond guides," and having sockets on the ends of the cross-heads sliding upon them; but the other plan is found to be most advantageous. In small stationary engines similar plans are also sometimes adopted; but in stationary and marine engines generally, the motion of the piston is maintained in a straight line by various combinations of rods, forming a parallel motion, which has less friction than guides, and is more convenient in those cases. The strain is also diminished by the piston-rod being connected with the end of a beam instead of directly with the connecting-rod, which has a much less irregular motion.

The two cranks are thus made to revolve uniformly by the action of the steam upon the pistons in the cylinders, and move with them the axle and the wheels fixed upon it. The wheels are made to revolve in the same direction that they would turn if the engine were running forward; and they cannot turn round without either slipping round upon the rails, or rolling forward upon them and moving the engine with them. If the adhesion of the wheels upon the rails is greater than the resistance of the engine to being moved, and the pressure of the steam be sufficient, the wheels will roll forward upon the rails; and the engine will be propelled, and be able to draw after it a load, the resistance of which is equal to the excess of the adhesion of the wheels upon the rails above what is required for moving the engine itself. The adhesion of the

wheels is not always the same; it is the greatest when the rails are most clean, and are either quite dry or quite wet; and it is least when the rails are dirty, and greasy with being partially wetted. For this reason an engine which is not loaded so much as the full adhesion of the wheels upon the rails, will often slip, and let the wheels turn round quicker than the engine is running, on passing a station, or any part of the line where the rails are liable to be dirtied by the traffic of persons across them.

The adhesion of the wheels is found to be about one-fifth of the weight upon them when the rails are in a good state, and it varies between that and one tenth or twelfth. The weight upon the driving wheels, as they are termed, is 6 tons, and the adhesion is therefore sufficient for drawing a load of 280 tons, besides the engine, upon a level. When the first locomotives were made, it was thought that the adhesion of the wheels upon the rails could not be sufficient to draw any load besides the engine, if it were enough for that; and various contrivances were resorted to, in order to obtain the necessary fulcrum from which to move the engine. Levers were tried, which resembled a horse's legs, and were thrust against the ground by the piston-rods; * a chain was also tried, lying on the ground between the rails, and taken hold of by a wheel in the engine; † also a rack was fixed inside the rails, and a toothed wheel, turned by the engine, worked in it.‡ Locomotives which are intended for conveying heavy goods have their adhesion upon the rails generally increased by coupling four wheels together, so as to make them all turn together, and thus obtaining the adhesion of all the four to assist in drawing the load. The power of the engine can then be increased, as the increased adhesion will enable it to be exerted; for the power of engines with only two driving wheels cannot exceed a certain limit, or it will be greater than the

* Brunton's Automatic Legs, 1813. See *ante*, p. 9.

† Chapman's Patent, 1812. See *ante*, p. 9.

‡ Blenkinsop's Patent, 1811. See *ante*, p. 9.

adhesion of the wheels, and the excess will be useless. The wheels that are coupled together are of the same diameter, and have connecting-rods attached to cranks, which are fixed on the axles outside of the wheels. Some of the old engines had their wheels coupled by a pair of cog-wheels, and also by an endless chain passed round a pulley on each axle.

The plan of driving the wheels of a locomotive by means of cranks upon the axle is attended by the disadvantages, that the axle is weakened very much by the cranks in it, and the power is applied at some distance from the wheels, where it is wanted. The action of the pistons upon the cranks, alternately pulling and pushing them, and the great weight that the cranked axle has to carry, make it necessary that it should be made very strong, in order to stand its work; they are, therefore, very heavy and expensive. They are very seldom broken, though they sometimes get bent by the engine running off the line; but the older locomotives had their cranked axles broken more frequently, as they were not made so strong at first. Several plans have been tried for obviating the necessity for a cranked axle, but they do not appear to be, any of them, so good upon the whole. The "Rocket," and some of the first locomotives upon the Liverpool and Manchester Railway, had their cylinders placed outside, and fixed above the wheels; and the connecting-rods took hold of crank-pins outside of the wheels, and fixed into them, so as to drive them directly. But it was found better afterwards to place the cylinders in the smoke-box, where they were protected from the air, which cooled them very much before; and the machinery could then be fixed more conveniently. Engines have also been made with vertical cylinders, which worked cranks outside the wheels by means of bell-cranks and connecting-rods.

Eccentrics.—Upon the cranked axle are fixed the four eccentrics, for the purpose of working the slide-valves. The construction of one of the eccentrics is shown in figs. 22 and 23, which are drawn to a scale of 1½ inch to a foot. Fig. 22 is a side elevation of an eccentric, and fig. 23 a section through

the centre of it. A is a portion of the cranked axle, 5 inches diameter; B and C are two cast-iron pieces, $2\frac{1}{4}$ inches wide, forming the eccentric, and each fitted half round the axle; the

Fig. 22.

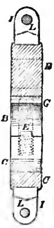
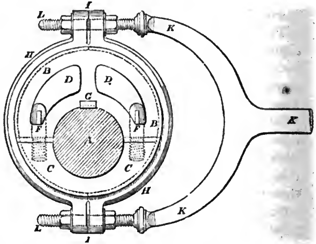


Fig. 23.



smaller one, C, being 1 inch thick in the middle, and the two pieces forming together a circle of 10 inches diameter. They have a projection of $\frac{1}{4}$ inch running round both sides of the outer edge, and the piece B has two openings, D D, cast in it, to diminish the metal, leaving a thickness of 1 inch on each side. A rebate E projects from the straight edge of the piece C, fitting into a groove in B to hold them steadily on each other; and the two pieces B and C are fixed together by the pins F F, which are firmly screwed into the piece C, and passing through corresponding holes in the other piece into the openings D D, are fixed by keys driven through them: the whole eccentric is then fixed upon the axle, so as to make them turn round together by driving the key G into a groove in both. The brass ring H H, 1 inch thick in the middle, is put in the groove round the eccentric, being made in two pieces, in order to enable it to be put into the groove, and the ends connected by flanches I I. K K is the eccentric-rod, forked at the end;

the ends of the fork being ⅝ inch screws, which pass through the flanches of the brass rings H, and hold them together by nuts upon the screws. The other ends of the eccentric-rods $e'' e'''$ and $f'' f'''$ * are carried on towards the smoke-box; and when the axle A revolves, the eccentric B C, revolving with it, turns round inside of the brass ring H H, which is prevented from revolving by the eccentric-rod that is fixed to it. The groove of the eccentric and the brass ring are both turned exactly to fit, allowing the eccentric to turn freely and steadily within the ring. As the eccentric projects from the axle more on one side than the other, the ring is pushed out further from the axle on that side; and in revolving with the axle, the ring is pushed out from the axle on each side in succession, causing the eccentric-rod to be moved in each direction from its central position as much as the projection or the eccentricity, which is 1½ inch, or 3 inches total motion or throw.

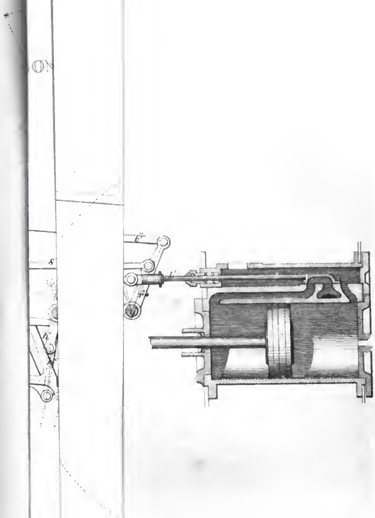
The action of the eccentric is precisely similar to that of a crank 1½ inch long; and the eccentric is, in fact, a crank with a very large crank-pin, this pin being 10 inches in diameter, and reaching beyond the axle itself; and the eccentrics are used instead of cranks, to avoid the necessity of making so many small cranks in the axle, though there is considerable loss of power attending the use of them from the friction being increased by their large size. Eccentrics are used for working the slide-valves in almost all steam engines, because of their convenience and steady action; they are also readily capable of adjustment, by altering the position in which they are keyed on the axle. They cannot be cast in one piece, as the cranks are forged with the axle, and the eccentrics have, therefore, to be put on in two halves.

SLIDE-VALVE GEAR.—A side elevation of the eccentric-rods and levers for working the slides is shown detached in figs. 1 and 2 in the Plate, facing in two different positions, with a cross section through the eccentric-rods, showing a back elevation of the levers, &c., in fig. 3. The two eccentrics

* See Plate facing page 66.

E$'$ are for working the slides when the engine is running forward; one being for the slide of the right-hand cylinder, and the other for that of the left cylinder; and the ends of the eccentric-rods, e'', are formed into large vertical forks, g'', having a notch in the bottom of each; the section in fig. 3 is taken through the notches. These notches take hold of steel pins, with shoulders to hold the eccentric-rod steadily, which are fixed into the lower ends of the levers h'' h''' by means of nuts screwed on at the other side. The levers h'' h''' are keyed on to the ends of the horizontal shafts or weigh-bars i'' i''', turning in brass carriages, k'' k''', fixed on to the frame of the engine, and made in two pieces, the upper part being loose, and held down upon the weigh-bar by bolts, allowing it to be tightened up as it wears. Upon the weigh-bars i'' i''', and standing above, are fixed the levers l'' l''', of the same length as the bottom levers h'' h'''; and two horizontal links m'' m''' are attached to the ends of each of these levers by a steel pin passed through them, with a small pin and washer at the end, to prevent its getting loose; the other ends of the links m'' m''' being attached in a similar manner to a socket on the valve spindle l', which is guided at its end by an eye in a small pillar fixed on to the boiler.

The eccentric-rods e'' e''', taking hold of the bottom levers h'' h''', make them move backwards and forwards with the eccentrics; and the top levers l'' l''', connected with them by the weigh-bars i'' i''', communicate the motion to the valve-spindles by means of the links m'' m'''; the levers h'' and l'' being of the same length, the motion of the slide-valves is the same as the throw of the eccentrics, or 3 inches, as before stated. The links allow for the oblique action of the top levers, which move in an arc of a circle, instead of a straight line, as the valve-spindle. The pins and eyes of the levers are all of steel, to diminish the wear, and are fitted very accurately, so as not to allow any shake when the motion is rapidly reversed at the end of each stroke, and that the slide may be moved the full 3 inches. The eccentrics are placed at right



Standidge & Co. Litho Old Jewry, London

angles to each other, that they may be both in the same relative position to the respective cranks; and they are fixed in such a position, with regard to the crank, that the port is full open, or the slide at the end of its motion, when the piston is at half stroke. The eccentrics are, therefore, at right angles to their respective cranks, and they have to be fixed a quarter of a revolution behind the cranks, in order to move the slides as much in advance of the pistons; because the levers h'' and l'' reverse the motion, so that when the slide has to be pulled back, the eccentric-rod must be pushed forward.

Reversing Gear.—The eccentrics E′ are placed so as to work the engine forward, and when the crank is down to cause the piston to be pushed back, and pulled forward when above the axle, and thus cause the wheels to turn round in the direction of the arrow, and propel the engine forward. In order to make the engine run in the opposite direction, two other eccentrics F′ are necessary, which are placed exactly in opposite directions to the former ones, or at the extreme back position, when the former ones are at their greatest throw forward; their rods f'' f''' have forks at the ends, similar to the other eccentric-rods; and levers, n'' n''', corresponding to them, are fixed on the other ends of the weigh-bars i'' i''', exactly like the levers h'' h'''. The four eccentric-rods have pins fixed into them below the forks, and attached to the suspending-rods o'' o'', o''' o'''; the two middle rods, o'' o'', for the working eccentrics, E′, being connected at the top to a cross-head at the end of the horizontal lever p'', and the other two, o''' o''', for the reversing eccentrics, forked at the top, and attached to the levers p''' p''', whieh extend in the opposite direction to the lever p''. The lever p'' is keyed upon the cross-shaft q'', and the other two, p''' p''', upon another shaft q''', both extending to the side of the engine, and turning in carriages, like the weigh-bars i'' i''', and having the vertical levers r'' r''' fixed upon their outer ends. The levers r'' r''' are connected by the link s'', attached to both; and one of them,

r'', extends above the joint, and is attached to the end of the long bar t'', extending to the back of the engine, and connected to a similar lever u'', upon a short shaft v'', which is fixed on the frame at the side of the fire-box. On the outer end of this shaft v'', and close to the hand-railing of the engine, is fixed the long handle w'', which moves between guide-plates attached to the hand-rail; the outer guide having a notch in the middle, to hold the lever w'' in a vertical position, and another at each extremity of the passage between the guide-plates.

In figs. 2 and 3 on the Plate, the lever w'' is shown pushed over into the forward notch, pulling the levers r'' r''' forward also by the bar t'' and link s'', causing the lever p'' to be raised by the means of the cross-shaft q'', and to pull up the ends of the eccentric-rods, e'' e''', by the suspending-rods, o'' o'', making the notches in them take hold of the pins in the bottom levers, h'' h''', of the weigh-bar. The two forward working eccentrics, E$'$, are thus put into gear, and made to work the slides of the two cylinders, and cause the engine to be propelled forwards. The other two lifting levers, p''' p''', are at the same time lowered by the lever r''' being pulled forward, letting down the rods f'' f''' of the reversing eccentrics by the suspending-rods o''' o''', so that their forks clear entirely the pins in the levers n'' n''', leaving them free to move with the weigh-bar, and in exactly opposite directions to the eccentric-rods f'' f''' below them.

When the hand-lever w'' is placed in the centre notch of the guides, or in a vertical position, as shown in fig. 1, the side levers r'' r''' are brought upright, and the lifting levers p'' p''' p''' made horizontal; so that the ends of the middle eccentric-rods are let down, and the notches in them escape from the pins in the bottom levers of the weigh-bars; and the outside eccentric-rods, f' f'', are only raised into a similar position, and are still not in contact with the levers of the weigh-bars. The slides will therefore cease to be worked, although the eccentric-rods continue moving, and the engine

will not be propelled any more, as the steam continues pressing upon the same side of the pistons.

But when the hand-lever w'' is pulled quite over into the back notch of the guides, the positions of the eccentric-rods are reversed; the outside lifting levers, $p'' p''$, being raised into the same position that the other lever, p', had before, and drawing up the ends of the rods $f'' f'''$ of the reversing eccentrics F′, to catch the pins in the levers $n'' n'''$ of the weigh-bar upon one of the inclined planes of their forks, and force them into the notches in the bottom of the forks. The reversing eccentrics are thus brought into gear, and made to work the slides, causing the motion of the pistons to be reversed by the steam being admitted on the opposite side of them, and making the engine run in the opposite direction to its former course; the middle eccentric-rods $e'' e'''$ are at the same time lowered, as the outside ones were before, allowing the forks upon them to clear the pins of the levers $h'' h'''$. The engine can then be propelled forward again by putting the hand-lever over into its front position, dropping the rods of the outer reversing eccentrics out of gear, and drawing up the inner rods of the forward working eccentrics, to force the levers of the weigh-bars into the opposite positions by their forks, and take hold of the pins in them.

The engine can thus be made to run either forward or backward by merely pulling the hand-lever w'' forward or back; and the handle is placed close to the engine-man, who stands behind the fire-box, so as to be readily moved: it is fixed so as to drop into the notches, and requires pulling out of them to shift its position, in order to prevent its jolting loose. The suspending-rods, $o'' o'''$, that support the ends of the eccentric-rods, have to be moved with the eccentric-rods in working, causing some friction to the engine: those rods that are in gear have to be held close up to the pins on the levers of the weigh-bars, that they may not get out of the notches in the eccentric-rods; and their motion does not exactly correspond with that of the pins in the levers of the

weigh-bars, from the suspending-rods taking hold below the notches of the eccentric-rods, and moving in an arc of a rather larger circle, causing a little additional friction from the sliding of the pins in the notches, though the amount of it is very small. To obviate this, the eccentric-rods are placed in some engines above the pins in the levers of the weigh-bars, with the forks and notches inverted, so as to drop down upon the pins and rest upon them when in gear, allowing the suspending-rods to have a loose hold of them, as they do not require support. This plan is liable to the objection, that if the eccentric-rods should accidentally get loose, by the pins jolting out, they would all fall into gear, and cause the breaking of the machinery, as they move in opposite directions: but with the other arrangement, the eccentric-rods would in this case merely fall upon a rod that is fixed under them across the engine.

This plan of reversing was first used by Messrs. Stephenson, and since adopted with different modifications by other makers. The former plan, in many locomotives, was to have the four eccentric-rods suspended above the levers of the weigh-bars in a similar manner to the last, but with notches only in their under side, so that they could not take hold of the lever-pins until they had moved along, and the notches coincided with the pins; the slides and levers being moved to the right position by means of two starting handles fixed on to the fire-box, and connected by rods and levers with the two weigh-bars; and these starting levers were always moving with the slides. This plan is inferior to the other with the forked eccentric-rods, as the slides have to be set by the starting handles, as well as the eccentrics reversed, in order to reverse the engine; though, when the engine is running, the first is not required; but a considerable strain is then caused by the eccentric-rods suddenly catching hold of the pins, and bringing them into motion.

The plan of driving the slides that was formerly much adopted, was by means of two eccentrics only, fixed together

at right angles to each other, and placed loose upon the centre of the cranked axle; their rods being connected with the weigh-bars, as in the other plans; and a driver with a projecting stud being fixed on the axle on each side, just clearing the eccentrics, and a hole made in each side of the eccentrics to fit the studs. The eccentrics could be shifted along the axle to either side by means of a lever, to make the stud in the driver on that side drop into the hole in the eccentric when it came opposite to it in revolving, and thus caused the eccentric to turn with the axle, and work the slides. The stud of the other driver was put on the opposite side of the axle to the corresponding hole in the eccentric; so that when the eccentrics were shifted to the other side by the lever, they had to stop for half a revolution before that driver caught hold of them, and were then fixed exactly opposite to their former position, and reversed the engine: in their intermediate position, when they touched neither of the drivers, they were stationary, and ceased to work the slides. This plan was inferior to those with four eccentrics, as it was not so certain in its action, and did not keep in order so well.

Working of Slides and Piston.—As the slides are worked by eccentrics, they are not suddenly reversed in position at the end of each stroke, in order to let the steam on to the other side of the piston, and keep the steam-port full open throughout the stroke; but are always in motion, and commence returning as soon as they have arrived at the end of their stroke. From this cause, they are obliged to have some travel, in order that the port may be full open for some time; and after having fully uncovered the port, the slides move or travel a little further, not beginning to close the port again until they have returned over the travel. The motion is very varying, as the eccentric drives the slides most quickly at the middle of its stroke, corresponding to the ends of the strokes of the piston, where the quickest motion is wanted, to admit the steam for the next stroke; the velocity of the slide diminishing rapidly towards the ends of its stroke, where it stops

and retrogrades. Many contrivances have been tried in stationary engines for working the slides more suddenly, either by striking the spindle with tappets or projections on a moving rod, or by means of different kinds of cams or eccentrics of irregular shapes: with these plans, travel of the slide would not be necessary, the port being full open nearly all the stroke.

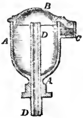
The piston and slides make two reciprocations or changes of motion during one revolution of the driving wheels; and as these are 5 feet in diameter, they make nearly four reciprocations per second when the engine is running at the rate of 20 miles an hour, and eight reciprocations in a second when running at a little more than 40 miles an hour: the ordinary rate of working is about five reciprocations per second. This extreme rapidity causes every change of motion to produce a violent blow to the machinery, requiring that all the parts should be very well made and fitted together, in order that they may stand the work: the greatest strain is produced upon the fixing of the piston-rod into the piston, and upon the joints of the piston-rod and connecting-rod. The brasses in the crank end of the connecting-rod are not keyed up quite tight, but a very little play is left, allowing them just to shake when worked backwards and forwards, in order to prevent their heating by the great rapidity of the motion, and expanding by the heat, together with the crank-pin, making the joint very tight: they have sometimes expanded so much from the heating, in consequence of being keyed too tight, that the engine has been nearly stopped by the great friction occasioned, and the brasses have been broken to pieces.

All the moving parts require a constant supply of oil to diminish the friction; and oil-cups are fixed for this purpose upon all the principal moving parts, such as on the ends of the connecting-rods over the bearings, on each of the piston-rod guides, and over the piston-rod and the slide-valve spindle; the piston is oiled by pouring oil into the cylinder by the cock in the cylinder cover, the bent end of the cock turning round

for the purpose. An oil-cup is shown, one-quarter the full size, in figs. 24, 25, and 26. Fig. 24 is a side elevation of it;

Fig. 24.

Fig. 25.



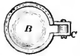


Fig. 26.

fig. 25, a section through the centre; and fig. 26, a plan of the top. The cup A is made of brass, and the cover B has a piece projecting from it, turning upon a pin in a socket C at the side of the cup A, and square at the end, resting upon a small spring at the bottom of the socket, to hold it either open or shut. An iron tube D is fixed into the foot of the cup, extending to the top, and projecting through the bottom, where it is screwed, for the purpose of fixing the cup on to the part which has to be oiled. The hole into which the cup is screwed runs through to the rubbing surface; and some cotton thread is put through the tube, dipping into the oil in the cup, and the other end touching the moving part; the thread acts as a syphon, and continually drops the oil upon the rubbing surface. The oil-cups were made at first without the tube or cotton thread; but the oil was found to run out too quickly, and could not be kept supplied: loose cotton was then put into the cup, to prevent the oil running out so fast; but the syphon cup acts much better, as it supplies the oil uniformly and gradually. The oil-cup on the crank end of the connecting-rod has so violent a motion, that it is almost impossible to

keep the cover shut, unless the spring is very strong: the covers are sometimes detached and screwed on, but they are then very liable to be lost; and the best cup for that purpose is one without a loose cover, but with only a small hole in the top, to pour in the oil, and made funnel-shape inside, to prevent the oil jolting out of the hole.

The faces of the slide-valves and the outside piston-rings are subject to considerable wear, from the pressure upon them and the rapidity of their motion; but the wear is very much increased when the boiler is supplied with dirty water, priming much in consequence; as the water which gets over into the cylinder carries particles of sand with it, which grind the rubbing faces very quickly. The slides in the engine referred to in this description have just been removed, having lasted two years; the old ones were worn down to less than $\frac{1}{4}$ of an inch thickness of flanch. The piston-rings are not yet worn out; they usually last about three years. In another engine that had run upon a part of the works, where the water was very bad and sandy, the piston-rings were worn down to $\frac{1}{8}$ of an inch thick in 4 months. The cylinders get worn uneven in time by the friction of the pistons, and require re-boring; about $\frac{1}{8}$ of an inch is taken off by the boring, and they are bored out generally two or three times before they are worn out; they wear usually for 4 years, before requiring to be rebored, but the time varies much with the quality of the metal, it being necessary sometimes much sooner.

A larger passage for the entrance of the steam is required in a locomotive than in a stationary engine, in proportion to the size of the cylinders; as the piston moves quicker, and the steam has to be admitted proportionally quicker. The best velocity for the piston of a steam engine is given by Watt as 220 feet per minute; and the area of the steam-port, so as to admit the steam to move the piston at that velocity with its full pressure, he gave as $\frac{1}{25}$ of the area of the cylinder. In this locomotive, the velocity of the piston when the engine is running at 20 miles an hour is 350 feet per minute nearly,

and at 40 miles an hour, nearly 700 feet per minute; the usual velocity being about 440, or double of the velocity in stationary engines. The size of the ports is one-fourteenth of the cylinder, or rather less than Watt's proportion, which would be one-twelfth and a half, as the piston moves twice as fast: the steam-ports in some locomotives are made as large as one-eleventh, and in others only one-seventeenth of the cylinder, but one-fourteenth appears to be a very good proportion.

The slide begins to open the steam-port a little before the commencement of the stroke of the piston, so that the steam is shut off from the piston and let on to the opposite side for the commencement of the next stroke, a little before the end of each stroke; acting for this interval in opposition to the motion of the piston. This is called the "lead" of the slide, and it is made generally about $\frac{1}{4}$ inch, being produced by fixing the eccentrics a little in advance of the position at right angles to the cranks. It is found necessary to let the steam on to the opposite side of the piston before the end of the stroke, in order to bring it up gradually to a stop, and diminish the violent jerk that is caused by its motion being changed so very rapidly as 5 times in a second. The steam let into the end of the cylinder before the piston arrives at it, acts as a spring cushion to assist in changing its motion, and if it were not applied the piston could not be kept tight upon the piston-rod. A little lead of the slide is also necessary, that the steam may be admitted through the port into the cylinder, and be completely ready to begin the next stroke when the piston is at the end of the cylinder; but so much is not necessary for this.

The principal advantage gained by giving lead to the slide is in beginning to get rid of the waste steam before the commencement of the stroke, so that when the piston commences its stroke, there is but little waste steam before it to resist its progress, the steam beginning to be let out of the cylinder before it has driven the piston to the end of the stroke. This is a very important point in a locomotive, as the resistance or negative pressure of the waste steam upon the piston is very

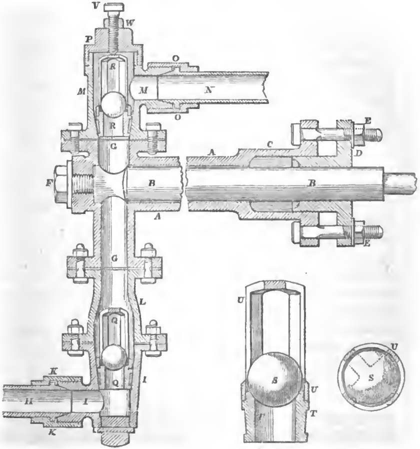
considerable, from the rapidity of the motion, which allows very little time for it to escape, and from the use of the blast-pipe, which obstructs its passage. The area of the extremity of the blast-pipe is only 5 square inches, while that of the steam-port is 8 square inches, requiring the velocity of the steam in the blast-pipe to be considerably greater than in the cylinder. The average negative pressure of the waste steam throughout the stroke is 6 lbs. per square inch when running at the usual rate of 25 to 28 miles an hour, and at greater velocities the negative pressure has been found to increase to double that amount, and even more. The effective pressure of the steam upon the piston at such high velocities is considerably below the full pressure of the steam in the boiler, as the steam cannot be supplied to follow up the piston so quickly with the full pressure, and the regulator has to be only partially opened, so as to throttle the steam and check its passage into the cylinders, which diminishes its pressure, as it has still to occupy the same space. The negative pressure of the waste steam amounts, for this reason, to 30 or 40 per cent. of the positive pressure of the steam upon the piston when the engine is running very fast, and the power of the engine is diminished nearly one-half.

For this reason an advantage is obtained by letting out the steam before the end of the stroke, and the steam still exerts a very considerable pressure on the piston to the end of the stroke, so that the whole power during the stroke is very little diminished though the steam begins to be let out before the end, and the resistance of this pressure of the waste steam during the next stroke is saved: the lead given to the letting out the steam, or the eduction lead, is often made greater than the steam lead, to increase this effect. The steam is shut off a little before the end of the stroke in consequence of the lead of the slide, and acts expansively for that portion, saving so much of the steam, but diminishing the total power a little: the extent of this action is, however, very limited, as the piston is less than $\frac{1}{4}$ inch from the end of its stroke when the steam

is shut off. In stationary and marine condensing engines the steam has usually very little or no lead, but it is shut off at two-thirds or three-quarters of the stroke, giving a great amount of expansive action, and the eduction has a great deal of lead, the port being nearly full open at the commencement of each stroke.

Feed-pumps.—The feed-pumps are fixed by means of flanches to plates, which are bolted on to the frame of the engine; they are fixed on the outside of, and a little below, the

Fig. 27.



F g. 28.

Fig. 29.

piston-rods, and exactly parallel to them. Each pump is worked by an arm, fitted on to the piston-rod; it has a socket at the end, fitted on the piston-rod, and fixed by a small pointed screw tapped into it and bearing against the piston-rod: the arm is inclined obliquely downwards, so as to clear the guides of the piston-rod as it is moved backwards and forwards by the piston-rod, and attached at the outer end to the plunger of the pump. One of the pumps is shown in section in fig. 27, to the scale of $2\frac{1}{4}$ inches to a foot. The barrel of the pump, A A, is made of cast iron, $1\frac{3}{4}$ inch in diameter inside, and $\frac{3}{8}$ inch thick. B B is the plunger, $1\frac{5}{8}$ inch in diameter, and made of a wrought-iron tube for the sake of lightness, plugged up at the inner end, and having a short rod keyed into the other end, which is fixed into the socket in the driving arm by a nut screwed on the end. The plunger B passes through a stuffing-box, C, at the end of the pump-barrel A, with a brass gland, D, attached by screws, E E, to the flanch of the stuffing-box. The plunger is turned truly cylindrical, to move water-tight through the stuffing-box, but the inside of the barrel of the pump is not bored, as the plunger does not touch it.

A plug, F, is screwed into the other end of the pump, to afford a passage quite through for the convenience of fixing. Two short pipes, G G, are cast upon the end of the barrel A, to the lower one of which is bolted the tube L, having the piece I fixed below it; both are of brass, and the piece I has a short tube cast on its side, with a screw made upon its outer end. H is the copper suction-pipe, having a brass collar soldered upon it with a thin conical end, which is fitted into the tube I, and held water-tight by the socket K, screwed on to the tube and bearing against the collar of the suction-pipe.

The piece M, which is bolted upon the upper pipe G, is closed at the top by a cap, P, screwed upon it, and has a tube cast on it like the bottom piece, I, into which the end of the delivery-pipe, N, is fixed by the screwed socket, O, exactly similar to the suction-pipe, H. The delivery-pipe is bent round backwards, extending to the fire-box, where it is fixed

into a valve-box, in the same manner as the other end is fixed: the pipe has to be bent in this way, that the ends may be turned in the same direction, to allow them both to be screwed into the sockets, instead of having the screws at the two ends pulling against each other. This box contains another valve like those in the pump, and is fixed on to the fire-box, communicating with the inside. The suction-pipes pass under the fire-box, and are connected at the end to the pipes that bring the water from the tender, being suspended by stays from the fire-box.

In the pieces L and M are fixed the valves Q and R, which are shown to double the scale in figs. 28 and 29, where T is the valve-seat, made conical and with a groove outside, to hold packing for fitting it water-tight when driven into its place in the pump. The valve, S, is a ball, turned and ground truly spherical, fitting water-tight into its seat in every position; it is guided by the piece U U, screwed upon the valve-seat, and cut into four bars, to allow passage for the water. A pin, V, is screwed through the cap P, bearing upon the guide of the valve R, and fixed by a set nut, W, to hold down the valve-seat and prevent its being raised out of its place by the force of the pump: the lower valve-seat does not require holding, as the pressure is above it.

The plunger B, fig. 27, is worked in and out of the barrel of the pump A, a distance of 18 inches, by the piston-rod, at each stroke, leaving a space behind it when drawn out equal to its bulk, which is supplied with water through the suction-pipe and lower valve, and the water again forced out through the upper valve and delivery-pipe into the boiler when the plunger is pushed in. The internal diameter of the suction and delivery pipes, and of the water-way in the valve-seats, is 1 inch. The pump would force a quantity of water into the boiler at each stroke, equal to the bulk of the plunger, for 18 inches in length, if the suction-pipes were kept open; but the quantity is regulated according to circumstances by means of cocks fixed in the suction-pipes, the handles of

which extend upwards through the foot-board on which the engine-man stands, so as to be within his reach; and the closing these cocks causes the plunger to leave a partial vacuum behind it, and as the water cannot enter to fill it up, so much less water is forced into the boiler. In small force-pumps a plunger is preferable to a piston, because the barrel does not require boring out, as would be the case if a piston were used, and the packing of the stuffing-box upon the plunger is much more easily kept in order than the packing of a piston.

The additional valve in the delivery-pipe acts in a similar manner to the upper valve cf the pump, and it is used as a security in case the other valve should get out of order from any dirt getting on its seat and preventing its closing. The valves first used for the feed-pumps were mitre-valves similar to the safety-valves, but ball valves are now used instead, and are found to be much superior, as they are more free and certain in their action, from requiring no spindle to guide them, and keep in better order. The plungers cf the feed-pumps are sometimes attached to the cross-heads, which are prolonged outside of the guide-blocks for the purpose, instead of being worked by an arm fixed on the piston-rod, but in both plans a considerable strain is caused, as the pumps are so much on one side of the piston-rod. To prevent this strain they have been worked by eccentrics fixed upon the axle in some large engines, in which plan additional friction is produced by the eccentric, but the friction caused by the strain is quite avoided, and perhaps more than compensates for it.

THE WHEELS, FRAMING, ETC., OF THE ENGINE.

WHEELS.—The wheels are of two kinds; the two driving wheels, which are fixed on the crank-axle, are 5 feet in diameter and are flat on the edge; the other four wheels, two of them placed towards the front, just behind the smoke-box, and the other two, at the back behind the fire-box, are 3 feet 6 inches in diameter, and have a projecting rim or flanch upon

their edges, which runs against the inner side of the rails. Each pair of the small wheels is fixed upon an axle, as well as the large wheels; they are $3\frac{5}{8}$ inches in diameter, and the outer ends project beyond the wheels, turning in brasses in the frame of the engine. Upon these brasses the whole weight of the engine rests through the medium of the springs above them; and all the weight is thus suspended by springs except that of the wheels and axles themselves, for the purpose of deadening the shocks that are caused in the rapid motion of the engine.

The construction of the wheels is shown in figs. 30, 31, 32, and 33, to a scale of $1\frac{1}{2}$ inch to 1 foot. Fig. 30 is a section through the centre of one of the small wheels, and fig. 31 is a cross section through the axle and nave; figs. 32 and 33 being similar sections of one of the driving wheels. A A is the axle of each wheel; the large one is $5\frac{1}{4}$ inches in diameter inside the wheel, and the small one is enlarged to 4 inches; the outside bearing, B, of both, is of the same size. C C are the naves of the wheels, made of cast iron; the large one is 18 inches in diameter, and the small one 13 inches; the length of both in the centre, where they are fixed to the axle, is $7\frac{1}{2}$ inches, and they are fixed by four keys, E E, each, driven into grooves cut in the axles and inside the naves. The wheels are entirely supported and held by these keys, as the naves do not touch the axle; and by this means a firm and uniform bearing can be obtained, and the wheels can also be fixed truly at right angles to the axle and at the proper distance from each other. Hollows, E E, are cast in the naves between each of the keys, to diminish the metal.

The rims of the wheels, F F, are of cast iron, $4\frac{1}{2}$ inches wide and $2\frac{1}{2}$ inches deep; they are cast with a groove round them on the outer side, to diminish the weight; bosses, G G, are cast on the inner side, where the spokes are inserted. The spokes, H H, are wrought-iron tubes $\frac{1}{4}$ inch thick, and tapering from $2\frac{1}{4}$ inches to 2 inches in diameter, and they are cast in the nave and rim. The spokes are inclined to the plane of

the wheel, so as to come nearly to one face of the nave and the opposite face of the rim; and they are inclined alternately in opposite directions, as shown in the figures, for the purpose of increasing the lateral strength of the wheels and preventing their bending and getting out of the vertical position with the great strains to which they are subjected. The spokes are laid in the moulds in which the wheels are cast, and the metal cast round them, the ends of the spokes being first plugged up; and the spokes are covered at the ends with a composition of borax, which causes them to partially melt when the metal is poured in, forming so close and firm a joint that they never get loose. The rims of the wheels are cast first, and allowed to remain for about three-quarters of an hour before the naves are cast, because they contract much more in cooling than the naves, being of a much larger diameter, tending to force the spokes nearer to the centre; and if the naves were cast at the same time, the spokes would be prevented from approaching the centre, and there would consequently be a very great strain upon them, and the metal in the rims would not set firm, from cooling in a state of tension, and would be liable to break with any blow; but by allowing the rims to set before the naves are cast, this action is prevented.

I I are the tires of the wheels; they are made of wrought iron rolled into the required shape, with the ends welded together; the plain one, for the driving wheels, is $5\frac{3}{4}$ inches wide, and the flanch-tire, for the small wheels, $4\frac{1}{2}$ inches wide. Sections of the two tires are given in figs. 34 and 35, half of the real size; they are both made slightly conical, being tapered from $1\frac{3}{8}$ inch to $1\frac{1}{2}$ inch thick; and the flanch projects $1\frac{1}{4}$ inch, and is $\frac{3}{4}$ inch thick at the edge, and 1 inch thick at the base. The rims and tires are both turned, and the tires are heated when put on, and contract in cooling, so as to hold firmly on the wheel: great care is required in fitting them, that they may not be loose upon the wheels, nor shrunk too tight, so as to injure their texture. They are held in their places by three bolts with countersunk heads in the tires, and

Fig. 30.

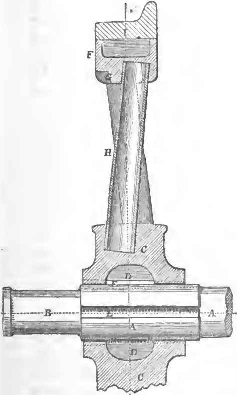
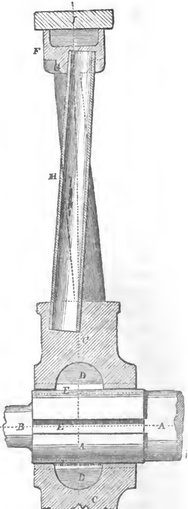


Fig. 32.



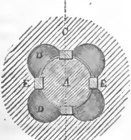


Fig. 31.

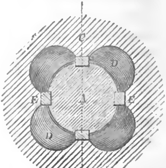
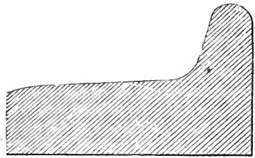


Fig. 33.

Fig. 34.



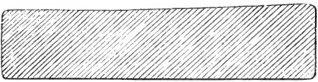


Fig. 35.

nuts screwed on against the inner side of the rims. The tires are turned when fixed on the wheels, to make them truly circular, and to make the two in each pair exactly alike.

The flanch-wheels, like the wheels of all railway carriages, require to be made a little conical, in order to prevent the flanches being continually in contact with the rails, and rubbing against them, which would cause a great deal of friction; as a wheel, when running towards one side and bringing the flanch in contact with the rail, will bear upou a larger circumference than the other wheel, and will tend to run towards the opposite side, and make the wheels central again: the flanches are thus hardly required on a straight line, and only necessary upon sharp curves, to keep the wheels from running off the line. The rails are laid inclined a little, so as to fit the conical wheels; and for this reason the driving wheels have to be made also conical, although they have no flanch. The driving wheels are made without flanches, that they may always have

firm hold on the rails, as a flanch on the inner one, when the engine is turning round a curve, would be forced against the inner rail, and would interfere with the bearing of the wheel, and cause friction; and flanches upon the front and hind wheels are sufficient to keep the engine upon the rails. For the improvement of making the middle driving wheels without flanches, Mr. Stephenson obtained a patent.

The wheels of the first engines were made entirely of cast iron, but it was found difficult to make them sound, in consequence of the unequal contraction in cooling, and they were too brittle to bear the shocks produced in running fast; the cast iron was also found to be too soft, and to wear in a groove on the edge with running on the rail; and the driving wheels could not be case-hardened, as the others were, from its diminishing the adhesion upon the rails. Wheels with wooden spokes and rims and wrought-iron tires were tried on the Liverpool and Manchester Railway, and found to wear better, being more elastic; and flat wrought-iron spokes were then tried. The wheels with tubular spokes, and cast-iron rims with wrought tires, are now very generally used, and wear very well, lasting two or three years; the driving wheels being subject to the most wear, in consequence of the slipping to which they are liable. The tires squeeze out at the sides as they wear, and when worn out are replaced by new ones; they are now made wider, the flanch-tires being 6 inches, and those of the driving wheels 7 inches, in order to prevent squeezing out at the sides, which is the greatest cause of their wearing out. The cast-iron rims are rather objectionable, from their brittleness, as they have to run with so great a velocity; and to obviate this, some engines have wheels with wrought-iron rims, to which the spokes are fixed by rivets, having the tires shrunk upon them: this construction is considerably more expensive, though very durable.

All the earlier locomotives on the Liverpool Railway were made with only four wheels; the third pair of wheels, placed behind the fire-box, were since added; but six-wheeled engines

are now in general use, and on most railways none others are used. In the earlier engines the fire-box was considerably smaller than the present size, and that end of the engine behind the crank-axle was but little heavier than the other end before the front axle, so that the engine was nearly balanced upon the axles, and ran steadily along.

The hind wheels in the six-wheeled engines support the fire-box, and prevent the pitching motion to which four-wheeled engines are liable. The springs over their axle are hung very light, so that in the ordinary state of the engine they only just bear against the frame, and take scarcely any weight away from the driving wheels, but they serve to catch the weight in the oscillations of the engine, and prevent that overbalancing which causes the pitching motion. The weight on the rails at these wheels is, therefore, only that of the wheels and axle, or about $1\frac{1}{4}$ ton when the engine is empty; and, when filled for working, the weight is about 2 tons, making the total weight of the engine 12 tons when full. The weight of the engine when empty is 10 tons, and that of the driving wheels and axle is about $1\frac{3}{4}$ ton, of which the cranked axle has nearly $\frac{1}{4}$ of a ton.*

When an engine is required for heavy work, as for carrying goods, and the adhesion of four wheels must be made use of for propelling it, the front wheels are made of the same size as the driving wheels, and coupled with them. The cylinders have then to be placed lower, and inclined upwards towards the cranked axle, in order that the piston-rods and guides may clear the front axle, as that is raised up to a level with the cranked axle and the former position of the piston-rod, by the wheels being of equal size. The driving wheels are in this case sometimes made less than 5 feet, in order to increase the power of the engine, as the diminishing of the diameter of the wheels diminishes the leverage of the load upon the

* It must be remembered that the weights here quoted, and also the sizes of wheels mentioned in the following paragraph, refer to the practice of the particular period described in the text.

engine, or increases the leverage of the engine in moving the load. But the speed of the engine is diminished in the same proportion, as the smaller wheels will advance a less distance than the larger ones in the same number of revolutions; but this is not material in the carrying of heavy goods, as so great a speed is not required for them. In order to enable the engines to run faster, without having to make more strokes in the same time, the size of the wheels has been increased, and a great many are now made with 6-feet driving wheels: the size of the cylinders has also to be increased to supply the increased power that is required, and they are made 13 inches diameter, with the same stroke, 18 inches.

Outside Framing, &c.—The principal or outside frame is placed along the sides of the engine outside the wheels, and across the ends, serving to support the whole engine, which is firmly fixed to it. It is made of good tough ash plank; the side pieces are 3 inches thick and 7 inches deep, and covered on both sides with sound wrought-iron plates, $\frac{1}{4}$ inch thick, fixed on by a number of iron bolts: the best plates are termed Low Moor plates. The side pieces are mortised into the end pieces of the frame; that in front of the engine being 5 inches thick, and 13 inches deep: angle pieces of iron are bolted on, to strengthen the corners inside and out. The outside length of the frame is 17 feet, and the width 6 feet 4 inches. The boiler, fire-box, and smoke-box are fixed to the side frames by strong wrought-iron stays, $4\frac{1}{2}$ inches wide, and half an inch thick. The stays, for the smoke-box and fire-box, consist of a horizontal piece, bent downwards at right angles at the inner end, and riveted to the side plate of the fire-box or smoke-box, and resting at the other end upon the side frame; the other inclined piece is welded on to it at the outer end, the two being bolted down to the frame, and it is riveted, like the other piece at the upper end, to the plate: the inner ends of both that are riveted to the fire-box and smoke-box are made T-shaped, and 12 inches wide. The stays for the boiler are made and fixed in a similar manner; they are longer, in order to reach the

boiler, and have a ring of the same sized iron inserted in them, touching the horizontal and inclined pieces of the stays and the sides of the boiler, and riveted to each of them.

Wrought-iron plates, $\frac{7}{16}$ of an inch think, are bolted on to each side of the frame at the axles, and called the axle-guides, serving to hold steadily the boxes that contain the brasses bearing on the axles, and to guide them when they slide up and down from the play of the springs. A piece $4\frac{1}{2}$ inches wide is cut out in the middle of each for the axle-box to slide in. These axle-guides have to resist all the strain of the wheels, and those of the driving wheels have to bear the whole force of the engine, which is moved along by the axle of the wheels. They are therefore strengthened by $1\frac{1}{4}$-inch rods fixed between each of them, with sockets across their ends, fitting between the two axle guide-plates, and fixed to them by bolts passed through both: the extreme rods are fixed to the end frames of the engine; the axle-guides for the small wheels have also bolts fixed through the bottom.

The axle-boxes in which the axles turn are all alike, and are shown to the scale of $2\frac{1}{4}$ inches to a foot, in figs. 36, 37, and 38. Fig. 36 is a section along the centre of one of them, fig. 37 is a cross section, and fig. 38 a plan of the top. A A is a cast-iron box, open at the bottom and the inner side, and $4\frac{1}{2}$ inches wide, so as to fit into the opening in the axle-guides. A hollow, B B, is cast in the top of the box A A, for the purpose of holding oil to supply the bearing, and in it is cast the socket C, in which the end of the spindle attached to the spring rests. The inside of the box is octagonal at the top, as shown in fig. 37, and has the brass piece D D fitted into it, which is turned out in the inside, to fit the end of the axle, reaching down to the centre, and having a small projection, E, on each side, which fits into a corresponding notch in the sides of the box A A, and serves to hold the brass steadily. Two thin brass tubes, F F, are screwed into the brass, and pass through holes in the top of the box A, projecting up into the hollow B, containing oil, and cotton thread is put into them,

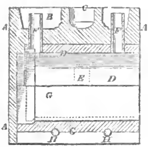


Fig. 36.

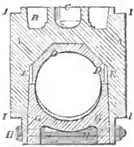


Fig. 37.

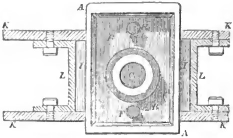


Fig. 38.

dipping into the oil and touching the axle at the other end, acting like a syphon in furnishing a constant supply of oil to the axle, as in the oil-cups before described. The bottom is closed by the cast-iron piece G G, made tapering to fit closely to the sides of the axle-box, and held in by the bolts H, and hollowed in the inside so as to clear the axle, the position of which is shown by the dotted lines. A piece, I I, is cast on each side of the box, projecting half an inch, which fits exactly between the two axle guide-plates, and slides between them, as shown in the plan, fig. 38, where K K is a horizontal section of the axle-guides; L L are pieces of iron plate bent so as to fit accurately between the plates K K, and bolted to them; the faces of the pieces I I bear against them, and they are both made true and smooth, so as to allow the axle-box to slide up and down easily and without shaking. The top of the box is

covered by a piece of sheet-iron, with a hole in it for the spindle of the spring, in order to protect the oil.

The springs are made, as usual, of separate steel plates: those for the driving wheels, are the strongest, consisting of thirteen plates, 4 inches wide, and $\frac{5}{16}$ inch thick; the other springs are 3 inches wide, the front ones having twelve plates and the hind ones eight. The four small springs are placed under the outside frame, and their ends rest in sockets fixed to the frame, and are kept in by bolts put through the sockets. The larger springs are turned over at the ends, and take hold of short bolts, having links fixed on them, the lower ends of which are fixed to cross-heads on bolts, which are put down through holes in the side frame and fixed by nuts underneath. A square iron socket is fitted on to the centre of each spring, and has a steel pin, $1\frac{1}{8}$ inch in diameter, fixed into its under side, the lower end of which rests in the socket on the top of the axle boxes, (C, figs. 36, 37, and 38,) and thus the frame which bears the whole weight of the engine is supported by the ends of the springs, which rest at their centres upon the axles of the wheels. The bearing pins of the middle springs pass through holes in the side frame, which serve to steady them when playing up and down; other pins are fixed in the upper side of the sockets on the other springs, which pass through holes in the frame above for the same purpose.

At the ends of the part of the frame in front of the engine are fixed the buffers; they are strong leather cushions stuffed with horse-hair, and are placed there for the purpose of deadening the shock of any collision with another carriage. Buffers are fixed upon each end of carriages of every description that run upon a railway, being all fixed at the same height and distance apart, in order that they may be the only parts of the carriages that ever touch each other: those on the engines are sometimes made with a large spiral spring inside, that their action may be more perfect. In the centre of the end frame is fixed a strong chain and hook, for attaching the

train of carriages when the engine is running backwards, a small iron plate being placed on each side of the frame for the bolt that holds the chain to be fixed against. A strong staple is also fixed into the frame on each side of the chain, as an additional means for attaching the train. The foot-board upon which the engine-man stands rests upon cross pieces of wood that are fixed to the piece of the outside frame at the back of the engine, and supported at the other end by a plate; a hand-rail is fixed on each side of the foot-board as a guard, and to one of these the guides for the hand-lever are attached. Two pieces of iron plate are placed across the back of the fire-box, and bent at right angles along one side, forming a flanch which is riveted to the back plate of the fire-box; they are also fixed at the ends to plates which are riveted on to the sides of the fire-box. Through the centre of the cross plates the draw-pin, $1\frac{1}{2}$ inch in diameter, is put, resting by its head on the top plate, and held by a key put through it under the bottom one; a socket is fitted on to it, having a pin projecting from it on each side, on which is fixed one of the links, which are attached in a similar manner at the other end to another socket, connected to iron bars fixed on the tender by a pin passed through them all: this pin is held by a key underneath, and is taken out when the tender is required to be disconnected from the engine. The socket on the draw-pin is supported by a small ring fixed by a set nut, and the link can by this means be readily adjusted level, so as to pull without side strain when the height is altered from the use of another tender or other cause. The draw-links are left free to move in any direction, in order to allow for the play of the springs of the engine and tender, and the oblique direction of the pulling round a curve; when they are disconnected from the tender, they can also drop down upon the edge of the plate. The draw-pin is required to be strong, to resist the great strain to which it is subjected; it is most strained when running down a considerable inclination, as the engine is not then con stantly pulling, but the train often pushes against it, and a

continued succession of violent jerks on the pin is produced in opposite directions.

INSIDE FRAMES.—Four wrought-iron frames are fixed between the smoke-box and fire-box, to afford additional strength to the engine by securing firmly the back plate of the smoke-box in which the cylinders are fixed, and which has to bear the whole strain of the working of the engine. These inside frames have also bearings in them for the cranked axle, and hold it steadily against the action of the connecting-rods, by which it is strained alternately in opposite directions. The frames are $3\frac{1}{2}$ inches deep, and $\frac{3}{4}$ inch thick; they are attached to the smoke-box and fire-box by means of T-shaped pieces of iron, which are riveted on to their inner and side plates, and are bolted to the ends of the frames; the two middle frames are made to approach each other, and are welded together at the back end, so that there are only three bearings on the cranked axle. On to the four frames are fixed the piston-rod guides, by means of pieces of angle iron, as before explained. The frames have to be inclined upwards towards the fire-box, in order to pass above the cranked axle.

The construction of the inside bearings of the cranked axle is shown in figs. 39, 40, 41, and 42, to the scale of $1\frac{1}{2}$ inch to the foot. Figs. 39 and 40 are side and end elevations; fig. 41 is a horizontal section through the centre of the bearing, and fig. 42 a plan of the top. The frame A A is increased at the bearing to $2\frac{1}{4}$ inches thick, the upper part B is $11\frac{1}{2}$ inches wide, and the lower part is formed into a fork, C C, 10 inches long, the sides tapering $1\frac{1}{4}$ inch in width. A tube, D D, is fitted between them, having a bolt passed through it, by means of which the two sides of the fork are held firmly together. Two iron wedges, E E, are fitted accurately to the sides, so that their inner faces are parallel to each other, and will remain parallel when moved up and down. Each side, C C, has a small projection on its inner side, fitting into a corresponding groove in each wedge, as shown in fig. 39, to guide it when moved, and a bolt, F, is carried upwards from each of

Fig. 39.

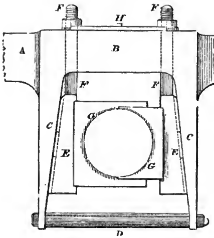
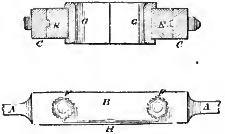


Fig. 40.



Figs. 41 and 42.

the wedges, E, through the upper piece, B, having a nut screwed upon it at the top; the holes for the bolts are made oblong, to allow for the lateral motion of the wedges when they are screwed up. The two brass bearings, G G, are inserted between the wedges, having flanches on each side fitted on the faces of the wedges; they are 3 inches wide, and bored out to 5 inches diameter, to fit the cranked axle. One of the brasses, G, overlaps the other, which is fitted steadily into it, but not quite touching at the ends. They are made to close upon the axle by screwing up the two wedges, E E, thereby forcing the

two brasses nearer together, and they are then free to slide up and down between the wedges to allow for the play of the springs, which affects the engine only, and not the axle, and are readily tightened up, as they wear from friction, by screwing the wedges up further.

The cranked axle is thus steadied against the horizontal force of the connecting-rods, which is the greatest strain that it is subjected to; but it can have no vertical support, in consequence of the play of the springs. A shoulder is made on the bottom of the nuts on the bolts F, and cut into teeth, as shown in the plan, fig. 42, which catch the ends of a small spring, H, fixed by a screw in the middle. This prevents the nuts from turning round and getting loose with the great jolting to which they are subject, the spring having to be forced out from each tooth in succession to let the nut turn; and though this does not impede the screwing up of the nuts, it is sufficient to prevent their getting loose. The same contrivance is applied to all the nuts in the engine that are used for the adjustment of some moveable part, as those in the glands of the piston-rod and slide-valve spindle, as these nuts are not screwed hard up so as to keep them fast.

Some engines with four wheels are made without the outside frame, and also have not the inner ones; and, instead of them, a strong iron frame is placed immediately within the wheels, bearing upon the axles, and having the whole engine resting upon it: this gives the engine a lighter appearance, as the wheels are quite on the outside. But the outside frame adds considerably to the stiffness of the engine, and is of great utility in that respect, particularly when the engine gets thrown off the line, as happens occasionally; when the outside frame serves materially to protect the machinery. It has also an advantage in enabling the engine-man to have access to any part of the engine whilst it is working, as the wheels and the space between them are covered over by the splashers, and can be readily passed over: this is very useful, as the working parts frequently require examining and replenishing with oil

whilst running. The friction is less when there is no outside frame, as there are but two bearings on the cranked axle instead of five; but they have to be the full size of the axle, as they are inside the wheels, which much increases the friction of each, and renders the whole friction but little less than in the other plan: the axle is also not held so steadily as with the middle inside bearings.

WHISTLE.—A steam-whistle is used for the purpose of giving warning of the approach of the engine when running; the construction of it is shown to $\frac{1}{4}$ size in figs. 43 and 44. It is

Fig. 43.

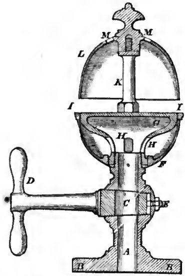
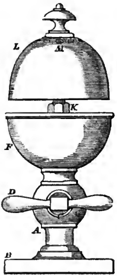


Fig. 44.



all of brass, and the foot, A, is cast hollow, with a flanch, B, at the bottom to bolt it upon the fire-box: it has a cock, C, placed in it, with the handle, D, and screw, E, to keep it tight; the handle projecting out to allow firm hold to be taken of it. The cup, F, is fixed upon the foot, A, by screwing the piece G upon it, and both are turned truly at their outer edges, leaving a very narrow passage, I I, 4 inches in diameter, between them all round. The piece G is hollow, having holes, H, in its

sides; and a pillar, K, stands upon its centre, on which is screwed the bell, L L, the thin edge of which is brought just over the opening, I, and $\frac{1}{2}$ an inch above it. When the cock is opened, the steam enters the cup, F, through the holes, H, and rushes out at the narrow slit, I, striking the thin edge of the bell, L, in a similar manner to the action in organ-pipes, and producing an exceedingly shrill sound: some holes, M, are made in the top of the bell, to allow the steam to pass freely through, which improves the sound considerably. The cock is required to be steadily opened, to adjust the quantity of steam, so as to produce the clearest sound. The steam-whistle is very effective, aud its sound can be heard at a great distance.

THE TENDER.

The tender is attached behind the engine and close to it; it contains a tank of water for supplying the boiler, and has a space in the middle filled with coke for feeding the fire.

FRAMING.—The side frames are made double, with diagonal bracing pieces inside them, and are connected by strong pieces at the ends. The floor is supported by diagonal and cross pieces, which are fixed into the sides and ends, and the joints of these pieces are strengthened by iron plates; the plate in the centre extending along each of them. An iron bar is fixed upon the bottom along the centre, and another bar bolted to it underneath at the front, the two projecting beyond the front, and having holes in their ends through which a pin is passed, to connect the socket at the end of the drawing links of the engine. A chain and hook are fixed on to the other end of the draw-bar, for the purpose of attaching the train of carriages: in this end of the bar a large square socket is made, and is fitted upon the middle of the long spring. The buffers are faced with leather cushions, and fixed upon iron spindles which pass through holes in the centre of two blocks of wood that are bolted upon the end of the frame: and the spindles have sockets in the outer ends, in which the ends of the long spring rest; and when the buffers

strike against those of another carriage, they press against the spring, which yields and reduces the shock of the collision.

WHEELS.—The tender runs upon four wheels, 3 feet in diameter, which turn in the space between the pieces of the side frames; they are made with flanches, and are similar to the small wheels of the engine. The wheels are keyed upon the axles, which are $3\frac{1}{2}$ inches diameter, and turn at their outer extremities in axle-boxes similar in principle to those of the engine; the axle-guides consist only of a single plate, each $\frac{3}{4}$ inch thick, bolted on to the inside of the outer pieces of the frame, and the axle-boxes have grooves cast in their sides, into which the edges of the axle-guides are fitted. The springs are fixed down upon the top of the axle-boxes by two bolts, made each into a large eye at the upper end, which fits upon the spring, and the ends of the springs rest in sockets fixed upon the under side of the outer piece of the frame. The tenders for the largest engines are often placed upon six wheels, to diminish the weight upon each wheel.

TANK.—The water tank is made of wrought-iron plates $\frac{1}{8}$ inch thick, riveted together and joined at the corners by angle iron; it is of a horse-shoe shape, 9 feet long, $6\frac{3}{4}$ feet wide, and $2\frac{1}{4}$ feet deep. It is supported upon the side and end frames and a cross piece in the middle, and is held in its place by pieces of strong angle iron fixed on to the frame and standing up to hold the front and back ends. The top of the tank is covered with a board, having sides of iron plate fixed upon it; and a raised part is made at the back, divided into three portions, covered with lids on hinges; the middle one containing an opening into the tank, 12 inches square, surrounded by iron plate brought up to the top, for the purpose of supplying the tender with water. The other spaces on each side are used as tool-boxes for holding the different articles that are constantly in requisition on the engine. A copper pipe is fixed underneath each end of the tank, communicating with it, and passing through the floor, having a cock in it to close the pipe when disconnected from the engine.

The hose-pipes that are attached to the suction-pipes, for the feed-pumps of the engine, are connected with them by screwed sockets or union joints, which can be readily unfastened when the tender has to be separated from the engine. The hose-pipes are made of leather or Indian rubber cloth, with a spiral spring inside, to keep them open, like the suction-pipes of fire-engines; a flexible pipe being necessary to allow for the variations of motion between the engine and tender. There is used sometimes, instead of the flexible hose, a metal pipe with a double ball and socket and a sliding joint, to allow motion in every direction: this has the advantage of not requiring repairs so often as the hose.

Coke.—The middle space of the tender is occupied with coke, the front end being made level with the foot-board of the engine, and a board fixed inclining from thence down to the floor, for the convenience of taking up the coke with a shovel to throw it upon the fire: the bottom and sides are covered with sheet-iron.

The Brake for stopping the wheels consists of two wrought-iron frames hung by pins from the side frame of the tender, and having blocks of wood fixed on to them, that are cut to fit the circumference of the wheels. A flat iron wedge fits into grooves in the two frames, and is continued up by a rod to the top of the tender, passing through a strong iron piece, and having a double handle screwed upon it. By screwing down the handle the wedge is drawn gradually up, and the two brakes are separated from each other, pressing the wood of each very forcibly against the wheels until they are stopped, if necessary. This brake is used to stop the engine and train quickly, and others are also used on the wheels of some of the carriages in the train: the brakes are of many different constructions, but this one is very simple and convenient, and has great power. A step and a handle are fixed on to the tender on each side, for the convenience of getting upon it or upon the engine.

HISTORY OF LOCOMOTIVE ENGINES SINCE THE YEAR 1838.

The clear and complete description of Mr. Stephenson's six-wheel engine just given, and which is, with only slight alterations and omissions of references, the same as prepared by Mr. W. P. Marshall (Secretary of the Institution of Mechanical Engineers), explains the construction and use of most of the essential parts of the improved locomotive engines even to the present time, while it is to be esteemed as a most full and authentic account of the large class of engines in use in the year 1838, and built from the same pattern.

Up to the year 1839, thirty-seven six-wheel engines appear to have been put on the Liverpool and Manchester Railway, the driving wheels being 5 feet in diameter, and the four carrying wheels 3 feet 6 inches. The cylinders of some of these engines had been increased to 14 inches diameter, and the stroke to 20 inches. The weights of the engines, in working order, had grown to more than 15 tons in some cases, while their speed and power had been so greatly advanced that their average duty was to draw loads from 150 to 188 tons at 20½ miles per hour. Their consumption of coke in performing this duty varied from ·26 to ·34 ℔. per ton per mile. Loaded to the extent of 25 tons, these engines attained about 30 miles per hour, and consumed from ·885 to 1·3 ℔. of coke per ton per mile. The quantity of water they evaporated for each pound of coke consumed, varied from 6 to 7·5 ℔s.

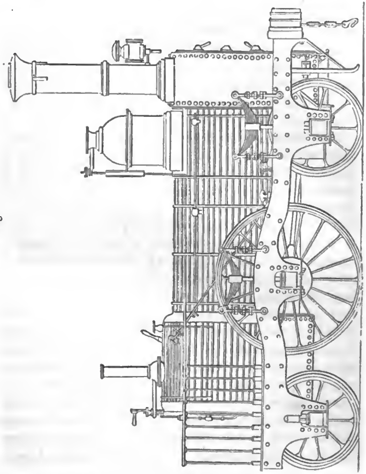
On the Great Western Railway, the increased gauge of the line (or width between the rails, 7 feet), and heavier carriages and loads to be impelled, at once afforded the means of introducing wider and more powerful engines than on the ordinary gauge (4 feet 8½ inches), and rendered this accession of power necessary. Forty locomotives were supplied on this railway to the year 1840, and all of these, excepting one only, had six wheels. The driving wheels of these engines varied from 6 to 10 feet in diameter, and the carrying wheels from 3 feet 6 inches to 4 feet 6 inches. One of these engines, named the "Morning Star," (built by Messrs. R. Stephenson and Co.,)

had cylinders of 16 inches stroke and 16 inches diameter. The boiler was 8 feet 6 inches in length, 4 feet in diameter, and contained 169 tubes of $1\frac{5}{8}$ inch diameter, exposing an area equal to 648 feet to the contact of the heated air. The fire-box, 3 feet $5\frac{1}{4}$ inches long, 4 feet wide, and 3 feet $10\frac{1}{2}$ inches high over the fire-bars, provided a surface for the action of the fire equal to $68\frac{1}{2}$ superficial feet. The weight of the "Morning Star" in working trim was described as being 12 tons, 12 cwts., and 2 qrs. The duty of the "North Star," another similar engine, built by the same engineers, was reported at 184 tons load, exclusive of engine and tender, at the rate of $32\frac{1}{2}$ miles per hour, for a distance (London to Maidenhead) of $22\frac{1}{2}$ miles.

The London and Birmingham Railway retained the use of four-wheeled engines till the year 1845, the locomotive superintendent of the line, Mr. Edward Bury, deeming them preferable to six-wheeled engines. The advantages of the former were described by Mr. Bury to be as follow:—"The four-wheeled engine is less costly than that on six wheels; it can be got into less space; is much lighter, and therefore, requires less power to take it up the inclines, and consequently leaves more available power to take up the train; is safer, as it adapts itself better to the rails, not being so likely to run off the lines at curves or crossings; is more economical in the working, there being fewer parts in motion, and less friction; those parts of the machinery which are common to both plans are more easily got at in the four-wheeled engine; the buildings and turntables are not required to be on so large a scale; as there are fewer parts in the four-wheeled engine, fewer tools, as lathes, drills, &c., are required; having fewer parts to be deranged, stoppages are not so likely to take place on the journey." Experience, however, was demonstrating, that, for high speeds, great loads, and severe gradients, four-wheeled engines were not so advantageous as those on six wheels; and when Mr. Bury's superintendence of the department ceased, the latter description of engine became adopted on the London and Birmingham Railway, as it had long previously been, for general passenger

traffic, on most other railways. In August, 1845, the stock of engines on the London and Birmingham consisted of 89 four-wheeled and 1 six-wheeled. The four-wheeled engines had cylinders from 12 to 14 inches in diameter, and 18 inches stroke; the driving wheels, 5 feet 6 inches to 6 feet diameter;

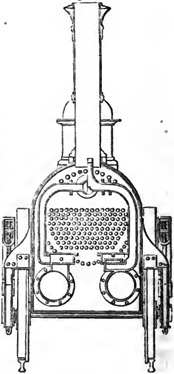
Fig. 45.



and the usual weight of the engines, when charged, was from $10\frac{1}{2}$ to $12\frac{1}{4}$ tons. The largest four-wheeled engines had 14 inch cylinders, and weighed 13 tons empty. The six-wheeled engines of that period may be illustrated by figs. 45 and 46,

which represent the side elevation and cross section of one of the best description.

Fig. 46.



The railway between Birmingham and Gloucester having been constructed with a very steep gradient, the "Lickey" Incline, of which the inclination for a length of 2 miles and 2·35 chains is 1 in 37, some locomotive engines for working the traffic up this incline were ordered from Philadelphia. These engines had a pair of driving wheels 4 feet in diameter and 4 front wheels, 2 feet 6 inches in diameter, attached to a "bogie" or swivel frame under the smoke-box, the wheels being thus attached with a view of enabling the engine frame to adapt itself to curves. The cylinders were inclined in position, $10\frac{1}{2}$ inches diameter and 18 inches stroke. The boilers had 78 tubes of 2 inches outside diameter, and 8 feet in length. These engines weighed about 8 tons when empty, or $9\frac{1}{2}$ tons when charged. Converted into tank engines, their weight was augmented to about 14 tons. Their usual performance up the "Lickey" was 33 tons at 12 to 15 miles per hour; $39\frac{1}{2}$ tons at $10\frac{1}{2}$ miles; or a maximum load of $53\frac{1}{4}$ tons, at $8\frac{1}{2}$ miles. On the Grand Junction Railway, Captain Moorsom reported that some of the American "bogie" engines propelled loads of 100 to 120 tons, on an incline of 1 in 330, at 14 to $22\frac{1}{2}$ miles per hour; or on an incline of 1 in 177, at 10 to 14 miles per hour. The mean of seven journeys from Birmingham to Liverpool, with gross loads of about 100 tons, showed a consumption of 50 lbs. of coke per mile, and an evaporation of

4·27 lbs. of water per pound of coke. A "bogie" engine of

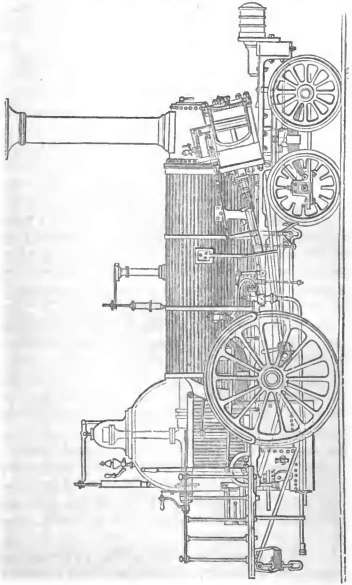


Fig. 47.

improved character is represented in fig. 47, in which the cylinders, &c., are shown in section.

The history of the locomotive engine having been thus sketched to about the year 1840, reference may be made to the Plates illustrating this part of the subject, and numbered I. to VII. in the accompanying Atlas of Plates.*

On Plate I. fig. 1 represents a six-wheel engine, with inside cylinders, adapted for the ordinary or 4 feet 8½ inches gauge, and for passenger traffic. In this engine the wheels are not coupled. The cylinders are enclosed in the lower part of the smoke-box, and the power is communicated directly from the piston-rods to the connecting rods, keyed on the cranks of the axle of the middle or driving wheels, which are 5 feet 6 inches in diameter, the four carrying wheels being 3 feet 6 inches. The general arrangements of this class of engine are very similar to those of Messrs. R. Stephenson's engine already described in detail, and illustrated so copiously with wood-cuts in our previous pages. These engines may be dated about the year 1838, when they constituted the ordinary form of six-wheel engines. On the same Plate, fig. 2 represents a six-wheel engine with outside inclined cylinders. The specimen here exhibited was built in 1839, by Messrs. Stirling and Co. of Dundee. The driving wheels were 5 feet, and the carrying wheels 3 feet 6 inches, in diameter. Boiler, 3 feet 9 inches diameter, containing 105 tubes, 8 feet 5 inches long, and 2 inches external diameter. Fire-box, 4 feet long, 2 feet 6 inches wide, and 3 feet 6 inches high. Chimney, 12 inches diameter and 6 feet high above smoke-box.

Fig. 3, on the same Plate, shows a small goods-engine on four wheels, such as used on some of the early Scottish Railways, laid to the gauge of 5 feet. Cylinders, 13 inches diameter, and 16 inches stroke. Wheels, 4 feet 2 inches diameter. Gross weight, 9 tons 6 cwt.; or net weight, 8 tons 1 cwt.

Fig. 4, on the same Plate, shows a large goods-engine on six wheels, the largest four of which are 4 feet 6 inches in

* See Atlas of Plates.

diameter, and coupled together. The two hind or trailing wheels are 3 feet 6 inches. Cylinders, 15 inches diameter. Stroke, 18 inches. Gross weight of engine of this class, 12 tons, or $10\frac{1}{2}$ tons net weight.

On Plate II. fig. 1 represents a "Bogie" engine, already described as being same as those imported into this country from America, for working the "Lickey" Incline on the Birmingham and Gloucester Railway. The cylinders are outside and inclined, 11 inches in diameter, and 18 inches stroke. The piston-rods work outside the wheels: the driving wheels are 4 feet in diameter, and the four bearing wheels are attached to a truck-frame called a "bogie" (turning on a pivot). These wheels are 2 feet 6 inches in diameter, and 3 feet distance between centres of axles. The tubes are 78 in number, 8 feet long, and 2 inches outside diameter. The net weight of the engine is 8 tons; with boiler and fire-box charged, 9 tons 11 cwt.

Fig. 2, Plate II., shows one of the four-wheeled engines for passenger traffic as used on the London and Birmingham Railway, and already briefly described. Cylinders, 12 inches diameter and 18 inches stroke. Boiler, 3 feet 4 inches diameter, 8 feet in length. Tubes, 90 in number, 2 inches diameter and 8 feet 4 inches long. Area of tubes. 396 feet. Fire-box, 3 feet 4 inches wide, 2 feet 6 inches long, and 3 feet 8 inches high above grate-bars. Area of fire-box exposed to fire, 43 feet. Wheels, 5 feet 6 inches and 4 feet in diameter.

Fig. 3, Plate II., represents a six-wheel engine as constructed for the original Irish gauge, or 6 feet 2 inches. The cylinders are 12 inches in diameter, stroke 18 inches. The driving-wheels are 5 feet in diameter, and placed between the carrying wheels, which are 3 feet 6 inches. Net weight of the engine, $13\frac{3}{4}$ tons.

Fig. 4, on Plate II., represents a four-wheeled engine as used for goods traffic on the London and Birmingham Railway. In size of cylinder and length of stroke it is the same as that shown in fig. 2 of same plate, but has a tube surface of only 345 feet,

and an exposed area of fire-box equal to 33 feet. The four wheels are all 4 feet 6 inches in diameter, and are coupled.

Plate III. represents a locomotive engine and tender as constructed for the ordinary gauge by Messrs. R. and W. Hawthorn, of Newcastle. The following are the general dimensions: Cylinders, 12 inches diameter and 18 inches long. Boiler, 3 feet 3 inches diameter and 8 feet long. Tubes, 121 in number, 8 feet 4 inches long and $1\frac{5}{8}$ inch in diameter; area, equal to $427\frac{1}{4}$ feet. Fire-box, 2 feet 6 inches long, 3 feet $5\frac{1}{4}$ inches wide, 3 feet $4\frac{3}{4}$ inches high above grate-bars, and having an area exposed to caloric equal to nearly 47 feet. Two wheels 5 feet 6 inches, and four 3 feet 6 inches, in diameter. Weight of engine, empty, $9\frac{3}{4}$ tons; in working order, 11 tons.

Plates IV., V., VI., and VII., contain elevation, sections, and details of the six-wheeled engines as used about the year 1840 on the Great Western Railway, and belonging to the same class which comprehended the "Morning Star," "North Star," &c., by Messrs. R. Stephenson and Co., already described, and other engines of approaching power and dimensions by Messrs. R. and W. Hawthorn; Sharp, Roberts, and Co.; Tayleur and Co.; Mather, Dixon, and Co.; and other makers. Of these plates, Plate IV. represents an elevation of the engine, Plate V. a longitudinal section, Plate VI. two transverse sections, and Plate VII. details. In these plates the same letters indicate the same parts throughout, and may be described in the following references quoted from Mr. Whishaw's work "On the Railways of Great Britain and Ireland."

E, *fire-box*, divided by a water channel towards the bottom, to obtain a larger amount of heating surface; XX, *grate-bars;* I, *fire-box door;* a a a, *tubes* extending through the boiler to the smoke-box; H, *steam-dome*, and G, funnel-pipe, *priming* being prevented by elevating the entrance to the steam-pipe above the surface of the water; F, *regulator*, by which the steam is admitted into the *steam-pipe* f, leading to the *steam-chamber* above the *cylinder* A; j and m, front and hind *steam-ports;* n, *piston;* k, waste-port; T, *slide-valve*, moved by

gearing shown enlarged in Plate VII., fig. 2. Leaving the cylinders, the steam escapes by the *blast-pipe*, M, into the *chimney*, R. The blast-pipe rests on, and is bolted to, a breeches-pipe (see Plate VI., fig. 1), which communicates with the *steam-chambers*, S S; o, *piston-rod;* r, *coupling-rod;* u, *crank;* t t, *axles* of the four bearing-wheels. O is the feed-pipe from the tank of the tender to the boiler; K, *man-hole* for examining the boiler; b, *safety-valve;* Q, *spring-balance* for showing the amount of pressure of steam, and within the reach of the engine-driver; L, safety-valve, beyond the reach of the engine-driver; c, *steam-whistle;* i, *cock* for emission of steam from cylinder when required; P, *cock* for emission of water from cylinder; W, *plough* for removing impediments from rails; N, *buffer* of carriage-frame; q, *coupling-chain*. The general dimensions of this engine are as follow:—Cylinders, 14 inches diameter, and 18 inches stroke. Boiler, 3 feet 9 inches diameter; 91 tubes, 2 inches outside diameter, and 8 feet long. Fire-box, 3 feet 3 inches long, 3 feet 6 inches high above grate-bars towards the tubes, and 3 feet 10 inches high towards the fire-door; width, 3 feet 6 inches; average height of water-channel, 19 inches, width 4½ inches, and length 3 feet 6 inches. Height of chimney above smoke-box, 6 feet 3 inches, and 15 inches in diameter. Steam-passage *induction*-pipe, 3 inches diameter; and *eduction*-pipe, 4½ inches; blast-pipe, 3 inches diameter. Driving wheels 5 feet 6 inches, and bearing wheels 3 feet 8 inches, diameter. On Plate VII. figs. 1, 3, and 4 show details of driving wheels; fig. 2, gearing for working the slide-valves; fig. 5, glass gauge for ascertaining the height of water in the boiler; fig. 6, section of steam-whistle; fig. 7, fire-box door; figs. 8 and 9, coupling-rods; fig. 10, angle-stay to secure the boiler to the carriage-frame; fig. 11, hand-pump, shown also in elevation, Plate IV. Figs. 12 and 13 represent longitudinal section and end elevation of a six-wheel tender, fig. 13 showing the brake for locking the three wheels on one side at the same time. Referring again to the engine, fig, 14 repre-

sents the cock, p, for letting off water from the cylinder, and fig. 15 shows the front of the regulator, F, with handle, d, as represented on the longitudinal section, Plate V.

On Plate VIII. are shown part longitudinal section and plan of a locomotive engine, with diagram of corresponding members of the apparatus, to indicate the *link-motion* which is now a most important part of the mechanism of the locomotive engine. It would be far beyond the limits of this little book, and, moreover, require an amplitude of intricate details intelligible only to professional readers, to attempt any history of the details of valves and methods of working them which have been from time to time proposed for or applied to the mechanism of locomotive engines. We must, therefore, be satisfied with a brief mention of the requirements that have led to the introduction of the link-motion apparatus, and with a brief description of that apparatus, as represented on Plates VIII., IX., X., and XI.

Up to the year 1838, or thereabouts, the mechanism of the valves of locomotive engines does not appear to have been designed with any view of altering the *rate of expansion* of the steam within the cylinders. The action of the valves, and the expansion they permitted, as used in 1838, have been already fully described. In or about 1839 it was found desirable to *vary* the rate of expansion at different parts of the stroke, and a form of gearing for effecting this is reported to have been first applied by Mr. John Grey to a locomotive engine on the Liverpool and Manchester Railway.

The overlap of $\frac{1}{16}$ inch in the valves has been already described, and the use of it explained in describing fig. 16. The amount of *overlap*, or "*lap*," as it is more familiarly called, determined, of course, the extent to which *expansion* of the steam was permitted, the expansion being understood to be an action of the steam within the cylinder *after* the steam has ceased to arrive, and before it has begun to depart. The lap of only $\frac{1}{16}$ inch left little time for exhausting the steam previous to the commencement of the return stroke, and the

necessary rapidity of the alternate strokes increased the evil effects of this imperfect exhaustion. By successive improvements in increasing the lap to 1 inch, the gross average consumption of coke per mile was reduced from 49lbs. to 28lbs.; and further improvements applied to new engines with enlarged exhausting passages, larger tubes, closer fire-bars, and superior construction, still reduced the consumption from 28lbs. to 15lbs. per mile, as appeared from the experience upon the Liverpool and Manchester Railway during the years from 1839 to 1844, reported by Mr. E. Woods. The economical value of the *increased lap* having been appreciated, the succeeding desideratum which almost naturally followed it, was such an arrangement of gearing as would permit the rapidity of the passage of the steam to be regulated by the position of the piston, or part of the stroke; in other words, an arrangement which would provide for a *varying expansion* of the steam. Mr. Grey's gearing for this purpose has been already mentioned. This was further developed by Mr. Williams, and practically introduced with such improvements as made it not only practicable, but deserving of retention since its introduction by Mr. Howe and Messrs. Stephenson in 1843. In this gearing the ends of the eccentric-rods are connected by a curved *link*, in the opening or *slot* of which a *sliding*-block, attached to the end of the *slide valve-rod*, is moveable. The ends of the eccentric-rods and the link may be moved vertically, and supported at any required elevation. The nearer that the centre of the link approaches the sliding-block, the shorter is the *travel* or stroke of the valve, and of course the greater is the amount of expansion.

In the diagram on Plate VIII. the connection of the slide-valve and rod are shown, also of the end or block of the slide-valve rod, the link, and the ends of the eccentric rods *a* and *b*. *c* and *d* are the eccentrics, *e* the connecting rod, and *f* the crank on the driving-wheel, *g*, from which the motion is thus derived for the eccentrics, and thence conveyed to the slide-valves. The straps marked *g* on the diagram, Plate VIII.,

are attached at their lower ends to a lever, shown in the section on same plate, and having a counter weight on the other arm of it. The fulcrum on which this lever turns is called the *weigh-shaft*, which is connected by side bars with the bar by which the backing of the engine is accomplished. By working this bar the engine-driver is enabled to raise the lower end of the lever, and with it the straps, link, and eccentric rods. As the link rises the effect of the motion caused by the eccentrics on the slide-valve rod diminishes until the centre of the link coincides with the centre of the slide-valve rod, when it ceases altogether. As the link continues to rise the motion of the slide-valve increases, but opposite to its former direction in reference to the cranks, as it now follows the motion of the lower eccentric arm instead of that of the upper one. Another arrangement of link-motion will be noticed in examining Plate IX

Plates IX. and X. show elevation and plan of the working gear of the "Pyracmon" engine, as an illustration of the goods engines on the Great Western Railway. In these plates the several parts are so described and figured, and their connections so clearly exhibited, that no further explanation will be required here, except for remarking that in this engine the link is shown as directly suspended from a stationary point, and a radius link is used for shifting the block on the slide-valve rod. The section on Plate IX. being taken through the steam-valve casing exhibits all the essential parts of the apparatus with great clearness.

Plate XI. represents the longitudinal section of an outside cylinder tank engine, as constructed for the Manchester and Birmingham Railway. On this plate the arrangement of the link motion with the valves and eccentrics is also very clearly exhibited. From a very complete description of this engine (as manufactured by Messrs. Sharp, Roberts, and Co.), written by Mr. H. B. Barlow, of Manchester, and published in the last edition of Tredgold on the Locomotive Steam Engine,* we

* John Weale, London.

quote the following description of the valves and links of this engine, and of the tank, &c., which it carries, and thus dispenses with the ordinary accompanying separate tender for coke and water.

"The extremities of the eccentric rods are forked, to take hold on each side of the link *x*, which consists of a segment provided with a radial slot, lined with steel, of about $13\frac{1}{4}$ inches long; the radius with which the centre of the slot in question is described being equal to the length of the eccentric rods, namely, 4 feet 7 inches. The pin which forms the connection between the rod *w'* and the link *x* is made of sufficient length to serve as a hinge to the flat bars *y*. These bars reach up to and are connected with the arms (1) of the reversing shaft *z*, which extends under the boiler from one side frame to the other. From the shaft *z*, and forged of one piece with it, projects the lever (2) for the counterpoising the arms (1), for the flat bars *y*, and the arm (3) to which the reversing rod is connected. The weight of the counterpoise must be equal to the weight of the links *x*, the flat bars *y*, and part of the eccentric rods; the object of it being to equalize the power to be exerted by the engine-driver when he wishes to reverse the motion of the engine: this will be more fully explained hereafter, under the head of '*Reversing Gear*.' A prolongation of the valve-rod, after passing through the stuffing-box in the steam chest before described, is keyed into a hollow cylindrical bush (4) of $2\frac{7}{8}$ inches in diameter. This bush is supported and guided by a bearing (5), which is bolted to the side frame of the engine: it terminates in a fork, and the link-block (6) is held between the forks of the bush (4) by means of a steel pin. In putting the link motion together it is necessary to place the link-block (6) in the slot of the link *x*, and to pass the pin into its place when the link, with the block, are in their proper position in the fork of the bush (4). In Plate XI. the two eccentric rods and the link are shown in the position for giving the greatest quantity of steam to the forward action of the engine; the link motion is shown in that

position which the various parts will assume when the engine is reversed, and the arms (1) and (2) of the reversing shaft *z* brought into the position indicated by the dotted lines on Plate XI.

"The bearing (5) is provided with brass steps through which the bush (4) slides, and the end of the valve-rod, to which the bush is keyed, is turned conical, to facilitate the taking asunder and putting together of the parts.

"*Reversing Gear.*—The reversing lever (7) vibrates upon a stud which is fixed to a bracket situated on the left side of the engine-driver when he stands on the foot-plate. To the end of the reversing lever is hinged one end of the reversing rod (8); the other end of it is connected wlth the arm (3) forged on the reversing shaft *z*; consequently every motion that is given to the reversing lever (7) is communicated by the rod (8) and shaft *z* to the link motion.

"The bracket on which the reversing lever hinges is made with two segments, between which the lever works; the inner segment being provided with thirteen equidistant notches to receive the end of a shot-bolt which is carried along the side of the reversing lever and hinged above to the reversing catch, the fulcrum of which is on the reversing lever: a spring acts upon the catch, and holds the end of the shot-bolt in the notches of the segment before mentioned. When the engine-driver wishes to alter the position of the reversing lever, he takes hold of the handle provided at the top, and, by acting against the catch at the same time, overcomes the resistance of the spring, so as to lift the shot-bolt out of the notch in the segment, thereby liberating the lever, which is free to move within the range of the segment. In letting go of the reversing lever, the engine-driver must take care that the end of the shot-bolt comes opposite one of the notches in the segment. In Plate XI. the reversing lever (7) and the other parts of the valve motion are shown in the positions they occupy when the valves are full open, and the engine is in the forward gear: when less steam is required, or when the engine

is reversed, the following changes take place in the relative positions of the parts: the slide-valve has now a traversing or backward and forward motion of $3\frac{3}{4}$ inches, because the link x is in its lowest position, and the slide-valve would receive the same amount of traversing motion if the engine were reversed and the link raised to its highest position: when the link is raised half-way, or in such a position that the eccentric rods are each at an equal distance from the centre of the valve-rod, the motion of the valve will be communicated by both eccentrics in an equal proportion, and the valve will only traverse through $2\frac{1}{2}$ inches. The steam in this case being admitted into the cylinder as much before the crank reaches the centre as after passing it, consequently there is no available force from the direct action of the steam; but there is, however, the force produced by the expansion of the small quantity of steam admitted into the cylinder, which is sufficient to keep the engine moving when the reversing lever is in its central position, although it would be quite insufficient to start the engine. By varying the position of the reversing lever (7), and consequently of the link, it is evident that the quantity of steam admitted into the cylinder may be increased or diminished at pleasure within the limits of the link. In working these engines the reversing lever is generally held by the second or third notch of the segment before alluded to, but in going down an incline the lever would be held by one of the notches nearer the centre of the segment; the exact position of the reversing lever depending entirely upon the speed required, the weight of the train, and the road that the engine is running upon, as well as upon the pressure of steam in the boiler and the position of the regulator.

"The utility of the counterpoise before mentioned is evident, as, without it, every time the position of the reversing lever (7) is altered, the engine-driver would have to overcome or resist the weight of the links x, the flat bars y, and part of the weight of the eccentric rods w.

"The advantages resulting from the use of the link motion

reversing gear, are, that by varying the position of the reversing lever the steam can be cut off at different parts of the stroke, and worked more or less expansively; the construction is more simple, and it is safer to reverse an engine at a great velocity, when worked by a link motion, than by any of the contrivances previously employed for that purpose. The link motion was first made by Messrs. Robert Stephenson & Co., about 1843, since which time it has become almost universally adopted by all the makers of locomotive engines in England and on the Continent.

"The Water Tanks are marked M and N, and are attached to the framing of the engine. The tank M, placed below the cylindrical part of the boiler, is 7 feet 2 inches long by 2 feet 10 inches deep and 2 feet 3½ inches broad, and recessed at one end so as to clear the axle of the leading wheels: it is supported at one end by an angle iron, riveted to the back plate of the smoke-box, and at the other bolted to a wrought iron beam extending from one of the side frames to the other, and supported in the centre by wrought iron brackets, riveted to the tank, and suspended by strong bolts passing through the brackets attached to the side frames. The end of the tank near the driving wheel is further supported by an angle iron resting on a cross stay, bolted to the stays (33), which connect the forks. There is also a beam passing from one side of the tank to the other, to strengthen it, and the tank can be detached in a very short time from the other parts of the engine.

"The tank N, placed below the foot-plate and behind the fire-box, is 3 feet 11 inches long, 2 feet 8¾ inches deep, and 4 feet in breadth; it is bolted to the side frames of the engine, and serves as a counterbalance to the weight of the fire-box, which is brought close to the axle of the trailing wheels. The two tanks, when full, contain 480 gallons of water, and are in communication with each other by means of the copper pipes O, which are fastened to the bottom of the tank N and to the sides of the tank M, the latter being placed 4¾ inches lower

than the former, and consequently containing about 30 gallons of water when the other tank is empty. The water is conveyed to the tank N through the vertical copper pipe (46) with a funnel-shaped top passing through the coke-box R, and seen in section in Plate XI.; the bottom of this pipe is closed with a perforated plate, and its sides, as far as they reach into the tank, are also perforated, so as to allow free ingress to the water, but not to any extraneous matter that might be carried into the pipe. This precaution is necessary to keep the valves in order; and when the perforations become choked up with dirt, &c., the whole pipe can be lifted out of the tank, and cleaned.

"The level of the water in the tanks is indicated by a float; this float consists of a piece of wood about 12 inches square and 3 inches thick, hinged at the end of a long lever, the fulcrum of which is attached to the side of the tank. A vertical rod is connected to the long lever in the tank, and is guided through a tube in the coke-box, beyond which it projects about 5 inches when the tanks are quite full; the projecting end is graduated, to indicate the level of the water, and is of great use to the engine-driver, who knows at a glance when he must take in water, and also when he must stop the supply, during the filling of his tanks. A bent copper pipe, 2 inches in diameter, is fixed on the top of tank M, to allow the escape of the air when the tanks are being filled. The man-holes, shown in front of the tank N, and at the bottom of the tank M, are sufficiently large to enable a man to enter for cleaning out or repairing when necessary.

"*Coke-box.*—R represents the coke-box placed over the tank N, and close to the engine-driver and stoker, who have about 2 feet 11 inches of space between the fire-box and the coke-box; its dimensions are 6 feet 4½ inches long, 2 feet broad, and 2 feet 11 inches deep, and the cubic contents, after deducting for the casing placed around the copper water tube, is 34 feet. The coke-box will contain half a ton of coke,

which quantity, added to the supply in the fire-box, when the fire is made up, is sufficient to take the engine with a train of from eight to ten carriages two journeys to Macclesfield and back. There is a sliding door, 24 inches wide and 16 inches deep, placed opposite the fire-door, through which the coke is taken out of the coke-box and shovelled into the fire-door. A very efficacious method of encouraging the engine-drivers to economize the coke has been introduced at the works of the London and North-Western, and other railways. The weight of coke received by each driver, and the number of miles run by his engine, are entered each day, and the number of pounds of coke to be used by each engine is fixed by the superintendent, according to the size of cylinders, the average weight of the trains, or the speed to be run: at the end of the month, the amount of miles travelled by each engine is divided into the number of pounds of coke consumed; and if the result shows that any engine-driver has worked his engine with one or more pounds per mile less coke than the quantity fixed by the superintendent, he receives a premium, varying from 2*s*. 6*d*. to about 30*s*. per month, according to the amount of coke saved.

"The engines Nos. 33 and 34 are computed to burn on an average 25 lbs. of coke for every mile.

"The consumption was, for

No. 33, in April, 1845, ...	25·20 lbs.
„ May, „	25·48 „
No. 34, „ April, „	24·58 „
„ May, „	24·36 „

"In taking the average consumption of these engines since they commenced running in May, 1847, the result shows that No. 33 has burnt at the rate of 26 lbs. per mile, and No. 34 has burnt 23 lbs. per mile, although the engines are constructed exactly alike.

"The accompanying extract from the books of the Long-

sight Works represents the average consumption per mile for every month.

		No. 33.	No. 34.
1847.	May,	30·41 lbs.	23·08 lbs.
„	June,	26·13 „	18·49 „
„	July,	23·38 „	17·92 „
„	August,	23·84 „	19·95 „
„	September,	25·43 „	20·82 „
„	October,	27·24 „	20·03 „
„	November,	27·46 „	25·81 „
„	December,	26·38 „	26·86 „
1848.	January,	25·69 „	26·25 „
„	February,	26·20 „	25·72 „
„	March,	26·11 „	26·16 „
„	April,	25·20 „	24·58 „
„	May,	25·48 „	24·36 „

"It will be seen from the above, that in July, 1847, the consumption of No. 34 was under 18 lbs. per mile, which, considering the number of stoppages on the Macclesfield line, proves very much in favour of these engines.

"Many of the engines on the Manchester branch of the London and North-Western Railway do not consume nearly so much coke as the above-mentioned sum of 25 lbs.; but the engines running the Macclesfield trains have to stop at nine intermediate stations, and therefore require more coke than engines running trains with fewer stoppages.

"*The Brake.* Upon a square at the upper end of a shaft is fixed the cast iron spoke wheel by which the screw is turned round. In Plate XI.* the blocks of wood are hidden by the section, but supposed to be in contact with the driving and trailing wheels of the engine: in order to remove the blocks from the surface of the wheels, the spoke wheel must be turned round so as to unscrew the end of the shaft out of the of the nut, thereby lowering the position of the bar, which, in descending, withdraws the brake blocks from the driving and trailing wheels. The screw on the shaft is made about 8

* See Atlas of Plates.

inches long, for the purpose of being able to bring the blocks of wood, even when worn away to the thickness of less than an inch, in contact with the wheels. This brake is found very efficacious in practice, as the screw above and the knee joints below have great purchase on the wheels, and are sufficient to arrest the progress of a train in a very short time. The blocks are made of elm, alder, birch, or poplar wood, and will last generally from two to six days, according to the state of the rails: fresh blocks are always kept ready at the engine-shed, and can be put on in very few minutes, by unscrewing two bolts to liberate the plate on which the worn-out blocks are fixed, and bolting on fresh plates with the new blocks attached."

Having thus given a description of the Tank Engine, and furnished a statement of its average consumption of water and fuel, as well as the work it had to do, it should be said in conclusion, that the work performed corresponded with the results obtained by calculation. For this purpose the formulæ developed by M. De Pambour, in his works entitled "A Practical Treatise on Locomotive Engines," * (2nd edition), and "The Theory of the Steam Engine," * were adopted, as being admitted to be based upon a correct view of the subject.

The following brief resumé of the latter experience in Locomotive Engines is gathered chiefly from "The Practical Railway Engineer" (4th edition).*

On the Grand Junction Railway, opened in 1837, and the South-Western, opened in 1838, the engineer, Mr. Joseph Locke, introduced locomotive engines which comprised several improvements in the details, due, it is believed, to Mr. Allan, of Crewe. These comprised—the removal of the cylinder to the outside of the smoke-box; the extension of the inside framing to the front end or buffer-beam of the engine, and abandonment of the outside frame; the attachment of the cylinder directly to the extended frame; the direct connection of the piston-rod with a pin in the nave of the driving wheel;

* John Weale, London. 1855.

the complete removal of the inside cranks, leaving the eccentrics and valve gear only to be arranged beneath the boiler; and involving, necessarily, inside bearings for all the axles. Subsequently it was suggested to retain an outside framing, making it of a single $\frac{1}{2}$-inch boiler plate on each side. The original locomotives constructed for the Grand Junction Railway, constructed in 1837, were six-wheeled, having inside cylinders from $12\frac{1}{2}$ to 14 inches diameter and 18 inches stroke; boiler, 8 feet long, weighing from $9\frac{1}{2}$ to 15 tons, when charged. Outside-cylinder engines, on the "Crewe" plan, or as altered by Mr. Allan and just described, were introduced as fast as the original inside-cylinder engines were worn out. The new ones had cylinders $13\frac{1}{2}$ and 14 inches diameter, and 20 inches stroke; wheels, 5 feet 6 inches and 6 feet; and weighed, when charged, from 15 to 16 tons. In 1851, the standard locomotive on the same railway was substantially of similar construction to the Crewe engine; and similar engines were adopted by Mr. Locke for the London and South-Western, the Paris and Rouen, the Caledonian, the Scottish Central, and other railways. On the South-Western Railway, Mr. J. V. Gooch introduced, in November, 1843, an outside-cylinder engine having $6\frac{1}{2}$ feet driving wheels, and he afterwards completed one for express trains on the same railway, having driving wheels 7 feet in diameter, the gauge of the line being 4 feet $8\frac{1}{2}$ inches.

In April, 1842, Mr. R. Stephenson patented his celebrated "long boiler" engine. Mr. Stephenson had already so well arranged the mechanism of his engine and economised space, that he found the 4 feet $8\frac{1}{2}$ inches gauge afforded ample width and to spare. In lieu of the levers previously used Mr. Stephenson effected a direct communication between the eccentrics and the valves, and he then proceeded to increase the power of his boiler by increasing the length of it from 8 to 12, 13, and 14 feet. If, with this length of boiler, the hind wheels had been placed, as usual, behind the fire-box, an immoderate length of bearing on the rails would have been the

consequence. To obviate this, Mr. Stephenson confined the bearing length of the wheels to 12 feet 9 inches between centres, his opinion being that this was the extreme length consistent with safety. In these engines the cylinders were arranged outside the smoke-box, and placed in the same horizontal line as the centre of the driving axle. In the year 1846 it was reported that at least 150 locomotives, according to this long boiler pattern, were in constant use in this country and on the continental railways.

During the use of the short boiler engines it was observed that a serious amount of destruction was going on in the "smoke-box" and chimney, both of which were not unfrequently red hot and the cylinders were sometimes split (defects which it became of the utmost importance to remove), and with a view to remedying these evils Mr. Robert Stephenson caused some experiments to be made to show the amount of heat which escaped, and subsequently invented the "long boiler."

The experiments were made at Derby in 1843. In the first instance, *tin* was placed in small iron conical cups and suspended in the "smoke-box," and was found to disappear quickly; next, *lead* was tried in the same manner, and was found to melt more easily; and, lastly, *zinc* was tried, which was soon driven off in vapour, clearly indicating a heat of 773° passing through the chimney, and that a waste of 400° at least was taking place. The "long boiler," by its greater and more gradual distribution of the heat, was designed to remove the above serious evils, and was found so far to answer as to show a heat in the chimney very little over 442°, as upon placing *tin* as usual, it was found just to melt at the corners only, or rather to "sweat" as it is technically termed.

Mr. Stephenson found that to obtain a patent for his invention would render it necessary to prescribe some definite arrangements of the engine, as the term "long boiler" was unlimited in its application, and to fix a length would afford no protection, as a few inches more or less would evade the

patent right; therefore, as an arrangement necessary and consequent upon the application of a "long boiler," the wheels were specified to be placed under the circular part of the boiler, the only suitable position, as in that day there were no turntables sufficiently large in diameter to admit of a greater distance between the couplings of the wheels than was determined by the above arrangement.

The "long boiler" and the position of the wheels constituted Mr. Stephenson's patent: but subsequently an improvement was made in it, which was to turn the cylinders over on their sides (their ports were opposite each other), in which position a direct communication was effected between the eccentrics and the slide spindles.

In these long boiler engines the driving wheels were placed between the fore and hind carrying wheels, the cylinders being kept forward to the outside of the smoke-box. This arrangement was found objectionable, as causing some unsteadiness at high velocities, such as 45 to 50 miles per hour; and to avoid this Mr. Stephenson produced a new design in 1846, in which the driving wheels were placed in the rear of the engine, and immediately in front of the fire-box, which thus overhung the wheel bearings. This arrangement admitted of the removal of the cylinders to a position between the carrying wheels. The most modern engines of this class have a total length of 20 feet, and length between extreme wheel centres of 12 feet. The boiler between smoke-box and fire-box is 13 feet 6 inches long and 3 feet 6 inches diameter, the cylinders are 15 inches diameter and 24 inches stroke, driving wheels 6 feet, and carrying wheels 3 feet 9 inches, diameter. The outside frame is dispensed with, the axle bearings are placed inside the wheels, and the frame is simplified with a rectangular plate $1\frac{1}{4}$ inch thick and 8 inches deep.

In 1842 a class of engines of increased power was introduced on the Great Western Railway. The sample of this class, named the "Ixion," has inside cylinders $15\frac{3}{4}$ inches diameter and 18 inches stroke; driving wheels 7 feet; four carrying

wheels; grate 13·4 feet; surface of fire-box 97 feet; tubes 2 inches diameter, 131 in number, surface 732 feet; total heating surface 829 feet; weight, empty, 22 tons; weight of tender, empty, 8 tons. Experiments made in December, 1845, upon this engine gave a maximum speed at the rate of 59 miles per hour with a maximum load of 76½ tons, and an average speed of 50 miles on a trip of 53 miles; the coke consumed was at the rate of 35·3 lbs. per mile, and water evaporated 201·5 feet per hour. In 1850 a yet more powerful class of engines, of which the "Great Britain" is the type, was introduced by Messrs. Brunel and Gooch. This engine has inside cylinders, and is supported on eight wheels. The cylinders are 18 inches diameter and 24 inches stroke; surface of fire-box 153 feet; surface of grate 21 feet; tubes, 305 in number, 2 inches diameter, surface 1799 feet; total heating surface 1952 superficial feet; driving wheels 8 feet; carrying wheels 4 feet 6 inches diameter; weight of engine, empty, 31 tons; of tender, empty, 8½ tons; total weight charged 50 tons. This engine evaporates 300 cubic feet of water at high velocities; load 236 tons at 40 miles per hour, or 181 tons at 60 miles per hour. Mr. Gooch considers this class of engine is capable of evaporating 360 feet of water without deviating from the proper proportions of its parts.

To solve the important problem of combining a large diameter of driving wheels with a low centre of gravity, Mr. T. R. Crampton removed the driving axle from beneath the boiler and placed it in the rear of the fire-box. He then lowered the boiler as far as the axles of the carrying wheels would permit, brought all the gearing to the outside, and increased the fire-box. In February, 1843, Mr. Crampton obtained a patent which included this arrangement of the driving wheels, and in 1847 two engines were accordingly built for the Namur and Liege Railway. The first of these, named the "Namur," was constructed with cylinders 16 inches diameter and 20 inches stroke; 182 tubes, 2 inches diameter and 11 feet long: surface of grate 14½ feet; of fire-box 62

feet; of tubes 927 feet; two driving wheels 7 feet diameter; four carrying wheels 3 feet 9 inches diameter; length between extreme wheel centres 13 feet. Experiments were made with this engine, before exportation, upon the London and North-Western Railway, over a total distance of 2300 miles, and its duty was found equal to 80 tons, exclusive of engine and tender, at 51 miles per hour on a level, and 50 tons at 62 miles per hour. In 1847 the first of Mr. Crampton's engines for the London and North-Western Railway was placed on that line, having cylinders 18 inches diameter and 20 inches stroke; 229 tubes, 2 inches external diameter and 12 feet long; surface of fire-box 91 feet; of grate $21\frac{1}{2}$ feet; of tubes 1438 feet; total surface 1529 feet; weight of engine, empty, 24 tons. The duty of this engine was found to equal 75 tons, besides engine and tender, at the rate of 55·4 miles per hour for a length of three miles, or 55 tons load at 53·4 miles per hour over a journey of 30 miles.

The dimensions of a trial engine built on Mr. Crampton's plan, named the "Liverpool," for the London and North-Western Railway, as a competitor on the narrow gauge, against the gigantic machines built for the broad gauge, are worth quoting:—cylinders 18 inches diameter, 24 inches stroke; 292 tubes, $2\frac{3}{16}$ inches external diameter, and 8 of $1\frac{3}{4}$ inch, 12 feet 6 inches long; surface of fire-box 154·434 feet; of grate $21\frac{1}{2}$ feet; of tubes 2136·117 feet; total heating surface 2290 feet; two driving wheels 8 feet diameter; six carrying wheels 4 feet diameter; length between centres of extreme wheels 18 feet 6 inches; total length of engine 27 feet; weight of engine, charged, 35 tons, or 12 tons on the driving wheels, 17 tons on the four leading wheels, and 6 tons on the two intermediate wheels; weight of tender 21 tons; total weight 56 tons. This engine conveyed the express trains between London and Wolverton for some time, and in one case took forty carriages within time, thus exceeding the combined duty of three ordinary engines. Its excessive weight and length, however, quickly threatened the stability of the permanent way, and

induced its retirement from active duty, without impugning its title, however, to be regarded as the "most powerful locomotive in the world."

At the Great Exhibition of the Works of the Industry of all Nations, held in Hyde Park, London, in 1851, one of Mr. Crampton's engines, named the "Folkstone," was exhibited, being one of eight, built upon the same plan, by Messrs. R. Stephenson and Company, for the South-Eastern Railway. The principal features in the arrangement of these engines were described to consist "in the boiler resting upon three points: one on the centre of a cross spring, which bears upon the axle-boxes of the driving wheels at the back of the fire-box, and one on each side in the front, on compensating springs, each of which springs bears upon the two axle-boxes of the small supporting wheels. The distribution of weight is for the purpose of preventing oscillation, and at the same time to insure, under all circumstances, an uniform weight upon each wheel, producing a greater amount of adhesion upon the driving wheels with a given weight than with ordinary engines. The other principal feature consists in communicating the power from the inside cylinders to a cranked axle attached to the frame, the same as in ordinary engines, and thence by means of coupling rods to the driving wheels behind the fire-box, the rods being arranged to act as counterweights to the inside connecting rods, &c., the proper balancing of which is of much importance. As the crank axle is not subjected to any blows produced by inequalities of the road or from the lateral movement of the wheels, the weight is reduced to one-half, and the liability to fracture from the above causes obviated. The driving wheels being placed behind, the torsion to which the driving axle is subjected while passing round curves is materially reduced, the cones of the wheels being properly in action, which is not the case when the driving wheels are in the centre of the engine." In the "Folkstone" the boiler is 4 feet 1 inch diameter and 10 feet 8 inches in length, two driving wheels 6 feet, and four bearing wheels 3 feet 6 inches in diameter. The

cylinders are 15 inches diameter and 22 inches stroke; the tubes, 184 in number, are 2 inches external diameter and 11 feet long; extreme length of engine framing 24 feet; between extreme wheel centres 16 feet. An engine of this class took 44 tons at a general speed of 65½ miles per hour, and attained a velocity at the rate of 73½ miles per hour upon a falling gradient of 1 in 264. In returning, the same engine ascended this incline with 95 tons load at the rate of 54 miles per hour.

The following is the specification for the "Liverpool" engine, quoted from Tredgold's Locomotive Engine,* and represented in Plate XII.:—

"*Framing.* The framing consists of two wrought-iron plates 1¼ inch thick, extending the whole length of the engine; to these are bolted transverse plates, also 1¼ inch thick, fixed as follows: one at each end of the double longitudinal framing; two immediately behind the fire-box, to receive the bearings of the driving axle; two underneath, which follow the curve of the barrel of the boiler, and serve, not only to add great rigidity to the framing at that part, but also form a convenient cradle on either side, to receive the cylinders: there is also another plate placed between the two front axles, and one at the extremity of the longitudinal double framing, which forms the 'buffer-beam' of the engine. Those under the barrel of the boiler are strengthened by means of angle-iron, as best seen in the longitudinal section.—*Boiler.* The barrel of the boiler is designed to receive the largest possible number of tubes, and is constructed of the best Staffordshire plates. As seen in the transverse section, the upper part would appear as a portion of a circle of larger diameter than the lower part; but the weakness of this irregularity of form is fully compensated by a series of transverse tie-bolts, 1⅛ inch diameter, and 8 inches apart from centre to centre: the centre-line of these ties is 2 feet 2½ inches from the bottom of the body of the boiler. The horizontal and vertical seams are

* John Weale, London.

overlapped by a belt, firmly riveted by double rows of rivets. —*Outside Fire-box.* The outside fire-box is swollen or bulged out at that part where it unites with the barrel of the boiler; and the lower part under the driving axle is extended 10 inches, for the purpose of increasing the amount of fire-grate surface.—*Inside Fire-box.* The inside fire-box is constructed of copper, and is provided with a mid-feather or water-space, the lower part of which is 7 inches from the surface of the fire-bars. The whole of the inside fire-box is securely stayed both at the top and sides, as shown in the longitudinal section.—*Fire-grate.* There are forty-four fire-bars, the area of which is 21·58 feet.—*Tubes.* There are 292 brass tubes of $2\frac{3}{16}$ inches diameter and 8 of $1\frac{3}{4}$ inch diameter, 12 feet 6 inches in length: these tubes are fixed perfectly tight by means of iron ferrules at the smoke-box end, and steel ferrules at the fire-box end. The total heating surface of the tubes amounts to 2136·117 feet, and the heating surface of the fire-box amounts to 154·434 feet.—*Smoke-box.* The smoke-box is made of the best Yorkshire plates; the front plate is supported by and secured to the double framing, and is provided with doors having proper fastenings.—*Chimney.* The smoke-box is surmounted by a chimney 18 inches internal diameter, and 13 feet 2 inches high from the level of the rails; it is parallel throughout: the plate at the upper part, which is splayed, is simply added to form an appropriate finish.—*Damper.* There is a damper, constructed after the manner of a Venetian blind, fixed in the smoke-box, at the end of the tubes: this damper is provided with a counter-balance weight and levers, as seen in the longitudinal section.—*Wheels.* All the wheels are made entirely of wrought iron: the driving wheels are 8 feet diameter, having bosses 17 inches diameter; the fore-wheels 4 feet 3 inches diameter, and the two pair of intermediate wheels are 4 feet diameter.—*Axles.* The driving axles are 7 feet diameter, with bearings 10 inches long; the other axles are 6 inches diameter, and have bearings also 10 inches in length.—*Axle-*

boxes. The axle-boxes are of the form shown, and are made of good hard brass; they are well fitted to their various pedestals, and accurately bored to receive the journals of the axles.—*Springs.* The springs are constructed in every respect similar to those represented in the Plate: it may be observed, however, that the weight of the fore part of the engine is equally distributed upon the four front wheels; and this is effected by means of a pair of springs, each spring having 12 plates, as seen in the longitudinal section.—*Cylinders.* The cylinders are 18 inches diameter, with a 24-inch stroke: they are cast free from every imperfection, and accurately bored to the required diameter: they are solidly fixed upon the transverse bearers, as before described. Each cylinder cover and bottom is provided with a cock, to aid the escape of any water which may have been formed by the condensation of the steam.—*Pistons.* The pistons are fitted with metallic packing, consisting of two concentric rings of cast-iron, each having a wedge and circular steel spring. The piston-rods are $2\frac{1}{2}$ inches diameter, and are made of the best Yorkshire hammered iron.—*Valves and Boxes.* The valves and boxes are formed as shown in the section. The boxes have a communication on either side with the regulator by means of copper branch steam-pipes.—*Main Steam-pipe.* The main steam-pipe is of wrought iron, 5 inches internal diameter, and 13 feet 6 inches long, having a slit $\frac{1}{4}$ inch wide along the top: it is suspended to the upper part of the interior of the barrel of the boiler.—*Blast-pipes.* The blast-pipes are of copper, and extend from the valve-boxes along each side of the boiler, and through the sides of the smoke-box, in which they unite, and terminate in a line level with the bottom of the chimney; the diameter at that part being $5\frac{1}{2}$ inches.—*Pumps and Rams.* The pumps are of brass; the rams are of wrought iron, $2\frac{1}{4}$ inches diameter, fixed in a line with the centre of the cylinders.—*Slide-bars.* The slide-bars consist of two bars 3 inches wide on each side of the piston-rod; they are made of the best hammered iron, and lined on the working faces with steel.—

Cross-heads. The cross-heads are made of the best hammered iron, and are firmly fixed to the piston-rods by means of cotters. The centre pins which receive the small ends of the connecting rods are shrunk on.—*Connecting rods.* The connecting rods are made of the best malleable iron, the smaller ends having brasses bored to 3 inches diameter, and the larger or 'crank-pin' ends bored to $4\frac{1}{2}$ inches diameter: the brasses are of the best metal, accurately fitted, and secured in their positions by means of cotters, as shown.—*Eccentrics.* The eccentrics are fixed to the boss of the driving wheels.—*Valve Motion.* The valve motion is that known as the 'link motion:' the blocks which work in the links or quadrants, as well as the various parts subject to wear, are case-hardened: the whole of the motion and levers are made of the best hammered iron.—*Buffers.* The buffers are of leather, well stuffed with curled horse-hair, and are firmly secured to the front plate or 'buffer-beam' of the engine: the distance between the centres of the buffers, transversely, is 5 feet 8 inches, and the height from the level of the rails to the centres 3 feet 3 inches. The buffers are fitted with a guide spindle, which works in a bush in the buffer-beam.—*Foot-plate and Hand-rail.* The foot-plates are 6 inches wide and $\frac{5}{16}$ inch thick, and made of the best Staffordshire iron; they are bolted to the outside framing, and extend nearly the whole length of the engine. The hand-rails are hollow, through one of which the rod which communicates motion to the damper fixed in the smoke-box passes.—*Felting, &c.* The barrel of the boiler, cylinders, and branch steam-pipes are covered with a coating of No. 3 hair felt, lagged with timber, and lined over all with sheet iron of the thickness of No. 17 wire-gauge, firmly secured with proper hoops, bolts, and nuts. The outside of the fire-box is also covered with felt, and lined with sheet iron of the same thickness as that covering the barrel of the boiler. There are syphons, syphon-tubes, pet-cocks for the pumps, glass gauges, whistle, drag-links, &c., made of the best materials. The whole of those parts of the engine which are not left bright are painted

with three coats of the best mineral paint, and finished with a coat of the best copal varnish."

In his "Reports on Railway Plant," Captain Huish has shown the successive extensions which have been effected in the weights and duties of the engines and carriages included under the general head of *Rolling Stock*. These Reports commence in 1831 on the Liverpool and Manchester Railway; and in 1837 on the Grand Junction, and London and Birmingham Railways, being the dates of their opening respectively. The reports are brought down to the year 1848 in each case, and the extreme results may be quoted as follows:—

		1831.		1848.	
		Tons.	Cwts.	Tons.	Cwts.
Weights	Of engines, average	7	0	18	13
	Ditto, greatest	7	0	37	0
	Of carriages, 1st class	3	10	4	6
	Ditto, 2nd class	3	5	4	1
	Ditto, 3rd class	3	0	3	18
	Of passenger trains, with engine and tender	18	0	76	0
	Of goods trains, ditto	52	0	160	0

		1831.	1848.
Speeds	Of goods trains, average miles per hour	10	20
	Ditto, greatest ditto	12	32
	Of passenger trains, average ditto	17	30
	Ditto, greatest ditto	24	50

As to the daily duty performed on each of these three lines, the reports show that the number of trains to and from the principal terminus of each railway respectively, viz., Manchester, Stafford, and London, during each period of twenty-four hours, had increased on the Liverpool and Manchester, from 26 in 1831, to 90 in 1848; and on the Grand Junction, from 14 in 1837, to 38 in 1848; and on the London and Birmingham, from 19 in 1837, to 44 in 1848. These few figures are quite sufficient to show how increased strength in the construction of the permanent way has become necessary, and how the

requirements of each year in this essential department of railway economy have exceeded those of the preceding year.

Mr. Joseph Beattie has introduced improvements in the locomotive engine, by which coal is economically used in connection with coke for the production of the steam, and also an apparatus for heating the water before supplying it to the boiler, and thus again economising the consumption of fuel.

Our notice of the locomotive apparatus of railways would not be complete if it omitted a description of the light engines constructed by Mr. W. B. Adams, who advocates, with great talent and practical knowledge, the economy of reduced weight in the rolling stock of railways. The first and smallest specimen of a light engine was built by Mr. Adams for Mr. Samuels, then resident engineer of the Eastern Counties Railway, for the purpose of enabling him to perform his professional inspections of the line without employing special trains, or wasting his time in waiting for the ordinary trains. After some experimental constructions the engine was completed, and performed a journey to Cambridge, with eight passengers, at the rate of 25 miles per hour. The following was the general construction and performance (see Plate XIII.). "The total length of the carriage is 12 feet 6 inches, including machinery, water-tank, and seats for seven passengers, all on one frame, which is hung below the axles, and is carried on four wheels 3 feet 4 inches diameter. The floor is within 9 inches of the level of the rails. It is propelled by two cylinders 3½ inches diameter and 6 inches stroke, acting on a cranked axle. The boiler is cylindrical, placed vertically, and is 1 foot 7 inches diameter by 4 feet 3 inches high. It contains a fire-box, 16 inches diameter by 14 inches high; with 35 tubes, 3 feet 3 inches long by 1½ inch diameter; giving 5½ feet of heating surface in the fire-box and 38 feet in the tubes. The water-tank is placed under the seat, and will contain 40 gallons.

"*Performances.* From the weekly statement kept of the working of this engine, it appears that the number of miles run during the half-year ending 4th July, 1848, was 5526;

and the quantity of coke consumed was 7 tons 9 cwts., being at about the rate of 3 ℔s. per mile. She has run altogether about 15,000 miles. The greatest speed attained on the level was 41 miles per hour. The ordinary speed that might be safely calculated upon for a long journey was 25 miles per hour. She has performed the journey from London to Cambridge, a distance of 57½ miles, in one hour and three quarters, being at the rate of nearly 33 miles per hour, with a consumption of coke 2¾ ℔s. per mile."

Subsequently the carriage was christened the "Express;" went down to Birmingham to be experimented on, and ascended the Lickey incline.

"The earliest practical recogniser of the advantages offered by the light system was Mr. C. H. Gregory, who advised the Directors of the Bristol and Exeter broad-gauge line to order, for some of their branch traffic, a steam carriage for first-class and second-class passengers. This was built by Mr. Adams, and called the 'Fair Field.' The vertical boiler of the 'Fair Field' was found to involve certain practical difficulties, though an exceedingly rapid and powerful steam generator, and was therefore replaced by a horizontal boiler."

The following are the particulars of the construction and the performance:—

"The 'Fair Field' steam carriage was constructed for the purpose of working the Tiverton branch of the Bristol and Exeter Railway, broad gauge. It is an engine and carriage on one frame, the extreme length being 40 feet, hung on six wheels, the two front ones being drivers, 4 feet 6 inches in diameter; the middle and trailing wheels are 3 feet 6 inches in diameter. Extreme centres of wheels, 28 feet. It is propelled by two cylinders, 8 inches diameter and 12 inches stroke, acting on an independent cranked shaft, communicating by side rods to the driving wheels. The boiler was originally cylindrical, placed vertically, and was 6 feet in height by 3 feet diameter. The fire-box was 2 feet 6 inches diameter,

with 150 tubes $1\frac{5}{8}$ inch diameter, with a heating fire-box surface of 20·6 feet, and 216 feet in the tubes. The tank is in front of the boiler, and will hold 240 gallons; it has since been fitted with a horizontal boiler, with a barrel 7 feet 7 inches long by 2 feet 6 inches diameter. The fire-box is 2 feet 6 inches by 2 feet 3 inches, and 4 feet in height; with 115 tubes, 8 feet long and $1\frac{1}{2}$ inch diameter. The heating surface in the fire-box is 37 feet, and 325 feet in the tubes.

"The body was divided into three compartments, one first class and two second class. Passengers, total number 58.

"*Performance.*—The Tiverton branch is 5 miles in length, and has a rising gradient of 1 in 86.

"The maximum load taken up this gradient was, exclusive of the carriage, 31 tons 13 cwts. 2 qrs. 16 lbs. in 11 minutes, being at the rate of over 27 miles per hour. Eighteen trips were run, being a distance of 90 miles, during a space of $9\frac{1}{4}$ hours, the running time being about $3\frac{3}{4}$ hours, and the standing time $5\frac{1}{2}$. The consumption of coke per mile 14·8 lbs. Subsequently it was reduced to 13 lbs., and the engine now works with 8·7.

"The load consisted of two loaded waggons each on four wheels of 4 feet diameter. The engine and carriages on six wheels, the whole train being on fourteen wheels, while the engine and tender alone of the Great Western engines occupy fourteen wheels without any carriages.

"The 'Fair Field' ran a trip from Exeter to Bristol, 76 miles—with an extra load of 10 tons behind her, equivalent to 140 passengers total—in 3 hours 37 minutes; 58 being consumed in twelve stoppages, leaving the remaining time 2 hours 39 minutes, being a fraction under 28 miles per hour. The maximum speed attained in this trip was 47 miles per hour."

The maximum speed ultimately attained was 52 miles per hour.

"After the 'Fair Field had made considerable progress, the Directors of the Eastern Counties Railway ordered of Messrs.

Adams a steam-carriage called the 'Enfield,' the form, proportions, and performance of which were as follow—as given by Mr. Samuels, in a paper read by him at the Institution of Mechanical Engineers:

"The 'Enfield' has 8-inch cylinders and 12-inch stroke; driving wheels, 5 feet diameter; distance between centres, 20 feet; width of framing, 8 feet 6 inches. The boiler is of the ordinary locomotive construction, 5 feet long by 2 feet 6 inches diameter. The fire-box is 2 feet $10\frac{1}{2}$ inches by 2 feet 6 inches.

"There are 115 tubes of $1\frac{1}{2}$ inch diameter, and 5 feet 3 inches in length, giving a total of 230 feet heating surface in the tube. The area of the fire-box is 25 feet, giving a total heating surface of 255 feet.

"The weight of this steam carriage is 15 tons 7 cwts. in working trim. The engine and carriage being combined, it is evident that the weight on the driving wheels is increased by the load carried, and that this weight increases in the same ratio as the load required to be taken.

"The extreme distance between the centres of the leading and trailing wheels being 20 feet, accounts for the steadiness of this machine; there is, indeed, no perceptible oscillation when travelling at the highest speed, and this verifies the observation 'that the steadiness of an engine depends not on the position of the driving wheel, but upon the length of the rectangle covered by the wheels.' This engine at the same time daily traverses curves of 5 or 6 chains radius.

"The 'Enfield' steam-carriage was originally intended to convey 84 passengers; but as it was found that when she was put on as an express train the passengers increased in number, a 'North Woolwich' carriage was attached capable of conveying 116 passengers, and also a guard's break-van, making provision altogether for 150 passengers, which is now her regular train taken at a speed of 37 miles per hour.

"The following return shows the miles run and coke con-

sumed by this engine during the $7\frac{1}{2}$ months regular working from January 29th to September 9th, 1849.

14,021	total miles run.		
705	hours, running time.		
1,457	ditto, standing time.		
2,162	total hours in steam.		
743	cwts. coke consumed in running.		
408	cwts.	ditto	standing.
286	cwts.	ditto	getting up steam.
1,437	cwts. total coke consumed.		
11·48	lbs. per mile average consumption of coke.		

"The 'Enfield' is in steam 15 hours per day, the fire being lighted about six in the morning and drawn at ten o'clock at night. But of these 15 hours it appears, by the return, that she is engaged running only 5 hours, the remaining ten being employed standing in the siding. It was found by experiment, that the quantity of coke consumed standing was 32 lbs. per hour; and after deducting this and the quantity consumed getting up steam, it will appear that the actual consumption of coke running is under 6 lbs. per mile.

"It must also be particularly borne in mind, that this consumption of coke includes the total goods and coal traffic on the branch, amounting to 1410 tons; viz., 169 tons of goods and 1241 tons of coal.

"The 'Enfield' steam-carriage worked the 10 A.M. passenger train from London to Ely, on 14th June, a distance of 72 miles, taking behind her three of the ordinary carriages and two horse-boxes; she arrived at Ely eight minutes before time, and the total consumption of fuel, including the getting up steam, was found to be $8\frac{3}{4}$ lbs. per mile. The tubes of the boiler are only 5 feet 3 inches in length, and the economy of fuel is consequently scarcely at the maximum.

"Another engine on a similar plan to couple with a 40-feet carriage is now nearly ready, the tubes being 6 feet 6 inches long, from which more economical results are expected.

"The result of the writer's experience is the conviction that, for express purposes and for the larger portion of the branch traffic on railways, the light steam-carriage is the best-adapted and most economical machine, both as to first cost compared to the work done, and in working expenses.

"The repairs of the permanent way are also very much reduced, as may be easily imagined.

"On the Eastern Counties railway an engine and tender of say 30 tons, a break-van, a first-class carriage, and three third-class carriages, conveying say 120 passengers, make a total weight of 59 tons, and the consumption of coke, as has already been shown, is on the average 34 lbs. per mile. A steam carriage weighing only 17 tons will transport the same number of passengers at from 7 to 8 lbs. of coke per mile when the best proportions are attained."

Our concluding Plate, XIV., represents the experimental engine with which several interesting and important trials were made in 1846 and 1847 by MM. Gouin and Le Chatelier, with the view of determining the value of the 'lap,' and other arrangements in the management of the steam in locomotive engines.* The engine represented is *la Gironde*, originally constructed at the Creasot, and afterwards partly reconstructed in the workshops of the Paris and Versailles Railway.

The following are the principal dimensions of this engine:—

	Feet.	Ins.
Diameter of the driving wheel	5	6
Diameter of the front wheel	3	6
Diameter of the hind wheel	3	6
Distance between the centres of the front and hind wheels	11	11½
Diameter of the cylinders	1	3
Stroke of the piston	1	6
Area of the piston . . . . . 176·715 sq. in.		

* Translated by Mr. R. Lloyd, and published by John Weale, London.

			Feet.	Ins.
Length of the cylindrical part of the boiler			8	3¼
Interior diameter of the boiler			3	11¼
Number of tubes	113			
Interior diameter of the tubes				1⅞
Interior diameter of the ferrules				1⅝
Length of the tubes			8	7⅛
Interior height of the copper fire-box above the fire-bars			3	9⅝
Height of the lower row of tubes above the fire-bars			1	7¾
Length of the fire-box			2	11⅞
Width of the fire-box			3	10½
Area of the surface of the fire-place	1659	sq. in.		
Area of the space between the eighteen fire-bars	915·2	sq. in.		
Sectional area inside the ferrules of the smoke-box	232·2	sq. in.		
Diameter of the chimney			1	3
Sectional area of chimney	176·2	sq. in.		
Height of chimney			5	10½
Area of direct radiating surface	8742	sq. in.		
Area of heating surface of tubes	71298	sq. in.		
Total area of heating surface	80040	sq. in.		
Total capacity of the boiler	138188	cub. in.		
Capacity of the space filled with water	72634	cub. in.		
Capacity of the space filled with steam	65485	cub. in.		
Weight of the engine when empty	35728 lbs. or 15·95 tons.			
Weight of the engine when full	37492 lbs. or 16·73 tons.			
Weight of the tender empty	13233 lbs. or 5·9 tons.			
Weight of the tender full	22055 lbs. or 9·8 tons.			
Interior diameter of the steam-dome				8⅞
Sectional area of steam-space	20·92	sq. in.		
Area of opening in the regulator	14·21	sq. in.		
Diameter of the steam-pipe				4⅞
Sectional area of steam-pipe	18·66	sq. in.		
Diameter of steam-pipes in the smoke-box				3⅜
Sectional area of steam-pipes in the smoke-box	8·95	sq. in.		

		Feet.	Ins.
Length of the steam-pipe from the face of the regulator to the valve-chest		7	4½
Height of the valve-chest		.	4⅛
Length of the valve-chest		2	1⅛
Width of the valve-chest		1	0⅛
Capacity of the valve-chest after deducting the volume of the valve	1868 cub. in.		
Length of the openings of the steam-ports		.	10¼
Width of the openings of the steam-ports		.	1¼
Sectional area of the steam-port		12	2
Its ratio to the area of the piston, $\frac{2}{29}$ or $\frac{1}{14 \cdot 5}$			
Width of the eduction port		.	4⅛
Area of the eduction port	42·3 sq. in.		
Sectional area of the eduction-pipe at its base	37·6 sq. in.		
Demi area of the eduction-pipe at its base	18·6 sq. in.		
Sectional area in the middle of the pipe	19·2 sq. in.		
Stroke of eccentric		4	0
Stroke of valve		4	0¾

ANTERIOR SURFACE OF PISTON.

		Ins.
Angular advance of the forward eccentric	38 degrees.	
Linear advance of the forward eccentric		1⅛
Exterior overlap		1¼
Interior overlap		¾
Lead of valve		¼
Advance of escapement		½
Conrse of piston during the expansion		5⅛
Course of piston during the compression		4½
Capacity of space left between the piston and cylinder-cover	309 cub. in.	

POSTERIOR SURFACE OF PISTON.

		Ins.
Lead of valve		¼
Advance of the escapement		⅝
Conrse of the piston during the expansion		6¼
Course of the piston during the compression		3⅜
Capacity of space left between the piston and the cylinder-cover	309 cub. in.	

Two light engines put on the Cork and Bandon line were of the following construction:—8-inch cylinders, 12 inches stroke, on four wheels; driving wheels, 5 feet in diameter; leading wheels, 3 feet diameter; distance between wheel-centres, 10 feet 6 inches; length of boiler-barrel, 9 feet 8 inches; diameter of barrel, 2 feet 4 inches; circular fire-box, 90 tubes $1\frac{5}{8}$ diameter; length of tubes, 10 feet. The two engines are christened by sonorous Gaelic names, corresponding, in plain Saxon, to "Running Fire," and "Whirlwind." The weight of these engines is $8\frac{1}{2}$ tons empty. They carry the water and fuel on their own frame.

The Engineer's Report, comparing the two classes of engines during five months' performance, from August 1st to December 31st, 1849, states that "The passenger trains are conveyed by the 'light' or small engines, which continue to afford the most satisfactory proof of their efficiency and economy in working the passenger traffic on your line.

"The trains frequently consist of the following stock, all fairly laden:—

"One large first and second class carriage for 58 passengers.

"One third-class carriage for 40 passengers.

"One horse-box for 3 horses.

"One carriage truck.

"Such trains are conveyed between Bandon and Ballinhassig stations in twenty minutes, being at the rate of 30 miles per hour, including stoppages. (Gradient, $3\frac{1}{2}$ miles, 1×100; total distance, 10 miles.)

"The daily consumption of coke for each of these engines has been registered as follows:—

	Cwts.	qrs.	lbs.
Consumed in lighting engine, time occupied 2 hours .	2	0	16
Consumed standing in steam, time occupied 8 hours .	2	1	17
Consumed in running 60 miles, time occupied 2 hours	1	3	26
Total daily consumption . .	6	2	3

Which is equivalent to $12\frac{1}{2}$ lbs. per mile per day of twelve hours;

but it will be seen that the running time is two hours, during which the consumption is not more than $3\frac{3}{4}$ lbs. per mile.

"The average daily consumption of the Company's ordinary-sized engine with the same work, is $22\frac{1}{2}$ lbs. per mile per day, or nearly double that of the light engines; and the same difference also arises between the two classes of engines in the consumption of oil, grease, &c., so that an important saving has been effected in the working expenses, by the adoption of engines whose powers and dimensions are in proportion to the loads they are required to convey."

We conclude this section by quoting Mr. Adams' Summary of the Mechanical Requirements of Railways, which summary embraces many of the most important objects to be arrived at in designing and constructing railway works and appliances, and is altogether a peculiarly practical and suggestive enumeration:—

"1. That the drainage be efficient, and substructure firm.

"2. That the sleepers, whether of wood, or stone, or metal, should possess sufficient bearing surface to prevent their crushing into the ballast beneath the rolling loads.

"3. That the surface-bearing of the rails on the sleepers should be as continued and extended as practicable.

"4. That the rails should be of such a section in vertical depth, that the maximum load on them may not induce deflection.

"5. That the rails should be of a width proportioned to the loads rolling over them, increasing the breadth as the load increases, on the same principle that a broad wheel is used with a heavy waggon on a highway. And that in case it be found advantageous to run very heavy engines, the upper surface of the rails should be steeled to resist abrasiou.

"6. That the joints of the rails should be so secured as to be immoveable beneath the rolling loads, yet permitting free expansion and contraction, so that there be no deflection, but an equable surface throughout.

"7. That on curves the rail should be bent by a machine,

so as to prevent the occurrence of tangential lines and sinuosities.

"8. That the maximum weight on the wheel tires of the engines and carriages should be considerably within the limit tending to produce deflection or abrasion of the rails, or crushing of the sleepers or substructure, or the treading out of the tires. Neglect of this causes enormous waste of steam power.

"9. That the construction of the engine should be so arranged as to keep the centre of gravity low, and the base extended, in order to prevent mischievous and dangerous oscillation.

"10. That the carriages and the waggon should be made as long and as wide as the curves and the width of the railway will permit, in order to prevent oscillation, and to economise space, material, and locomotive power in working.

"11. That each carriage or waggon should maintain steadiness by its length, without trammelling the wheels, which should be free to move laterally, to suit the curves or inequalities of the rails, and avoid friction.

The following interesting statements of Cost of Locomotive Engines on the Lancashire and Yorkshire Railway, cannot fail to be interesting.

COST OF LOCOMOTIVE ENGINES.

Statement of Materials, Value, Wages, supplied to make a Passenger Engine and Tender.

	No.	T.	c.	qrs.	lbs.	Rate.	£	s.	d.
Axles	5	1	9	2	17½	23s. 6d.	34	16	11½
Castings, Brass	..	1	6	1	8	0 10	122	16	8¾
Castings, Iron	..	2	4	0	16	10 0	22	1	5½
Ditto, Cylinders	2	1	4	0	10	21 0	25	5	10
Copper	..	1	0	1	1¼	0 10½	99	5	8½
Wrought Iron	..	20	8	0	16½	14 0½	286	12	0½
Steel	..	..	10	2	27¼	20 4½	10	17	2¾
Tubes, Brass	116	1	6	1	0	0 10	122	11	3
Tire Bars	10	2	16	0	3¾	28 11½	81	1	9½
Ball and Socket Joints, Cocks, Whistle, Syphons, Timber, &c.	..	..	..	..	..	..	51	14	0
Files, Materials for repairing tools, Small Stores, Coals, &c.	..	..	..	..	..	1 0	122	8	11½
							979	11	11½
Wages	..	..	..	..	..	..	648	1	5½
							1627	13	4¾
Say, add for proportion of current expenses in Rent, Taxes of Shops, Lighting, Repairs, &c., &c., average of Twenty Engines	..	..	..	..	..	..	120	0	0
						say	1748	0	0

COST OF LOCOMOTIVE ENGINES.

STATEMENT OF MATERIALS, VALUE, WAGES, &c., SUPPLIED TO BUILD A GOODS ENGINE AND TENDER.

	No.	T.	c.	qrs.	lbs.	Rate.	£	s.	d.
Axles	5	1	19	0	17½	35s. 0d.	69	12	10
Castings, Brass	..	1	3	2	22½	0 9	99	3	7½
Castings, Iron	..	2	16	2	11¼	8 7	24	6	0
Ditto, Cylinder	2	1	0	1	24¾	18 0	18	8	3¾
Copper	..	1	7	0	20¼	0 10½	135	4	9½
Wrought Iron	..	24	4	0	17½	13 10½	294	2	8¾
Steel	..	1	6	1	3	17 9½	18	19	0
Brass Tubes	136	1	7	1	3¼	0 9¾	124	4	10½
Tire Bars	10	2	13	3	13¾	29 11	80	11	9½
Brass Ball Clacks, Ball, Socket Joint, Cocks, Whistle, Syphons, Spring Balance	..	..	..	..	..	..	22	15	3¼
Firebars, Timber, Files, Paints, &c., &c.	..	..	..	..	..	..	139	7	3¼
							1026	16	3¼
Wages	..	..	..	..	..	..	466	14	0¼
							1493	10	3½
Say, add for proportion of current expenses in Rent, Taxes of Shops, Lighting, Repairs, &c., &c., average of Twenty Engines	..	..	..	..	..	..	120	0	0
						say	1614	0	0

Railway Wheels.—The wheels for railway carriages being a most important item in railway expenditure, and, viewed in respect of public safety, claiming not only professional, but public, attention and anxiety, we have gladly embraced an opportunity of incorporating in this work, intended for general information, a description of some of the latest and most useful improvements introduced in the construction of wheels for railway purposes.

A very excellent description, by Mr. H. B. Barlow, will be found, fully illustrated, of all the early inventions in this department, in a work entitled, Railway Engine and Carriage Wheels. This work brings the description down to the year 1847. Our example is of more recent date, and has enjoyed sufficient trial to be entitled to be now considered an established and approved example.

DESCRIPTION OF MANSELL'S PATENT SAFETY WHEEL.

The merits of this wheel for railway purposes are its safety and economy, combined with simplicity in its construction and repairs, which advantages may be enumerated as follows:—

1st. Safety in the event of a tire breaking, even should it break into a number of pieces, as under such a circumstance not any piece can leave the wheel, which would still remain efficient for travelling without risk or danger to passengers, or mischief to the train. Experience has satisfactorily proved this.

2nd. Less liability to fracture of the tires than exists in any other description of wheels, in consequence of their being fixed in a cold state with equal strain throughout their circumference, and without any holes through them.

3rd. Greater durability and amount of wear in the tires, which on these wheels may be used much thicker, and worn

much thinner than on any of the ordinary descriptions. Tires made of steel or other very hard and lasting material, may be used on these with perfect safety; even chilled cast-iron tires are in satisfactory use thereon.

4th. The body of this wheel being a cylindrical disc, equally supports the tire throughout its circumference, and cannot be flattened or pressed out of true figure, consequently preventing the destruction of tires, which get turned down or rather cut away in a lathe, to make them cylindrical after a yielding of spokes and consequent flattening of periphery, which frequently takes place in all wheels with tires shrunk thereon.

5th. Less liability to fracture of the axle, owing to the diminution of vibration on concussions, by reason of the timber disc or body materially reducing, if not wholly absorbing, its crystallizing and mischievous effect on the axle.

6th. Simplicity of construction and repair, by reason of its material being wholly prepared and put together by the agency of machinery, which secures for it uniformity and the greatest accuracy of construction without any fitting by manual labour.

7th. This is also a true balance wheel, which feature deserves consideration in its influence on the wear and tear of both road and vehicles.

Fig. 48. Front Elevation.

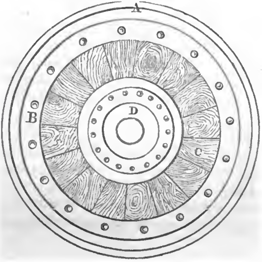


Fig. 49. Cross Section.

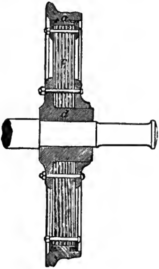


Fig. 50. Inside Elevation of Securing Ring.

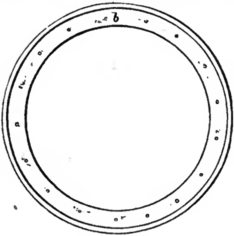


Fig. 51. Front Elevation of Tire.

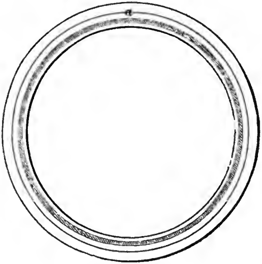


Fig. 52. Cross Section of Tire.

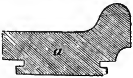


Fig. 53. Cross Section of Securing Ring.

Scale of Figs. 48, 49, 50, and 51.

Scale of Figs. 52 and 53.

EXPLANATION OF THE DIAGRAMS.

In the front elevation, fig. 48, A represents the tire, B the front securing ring, C the timber disc or body, and D the boss, the same parts being represented in each figure of detail by corresponding letters in italics.

The tire is perfectly parallel, being bored conical on the inside periphery, and is provided with a cylindrical groove on each of its sides (as shown by fig. 52) cut to gauge, into which are fitted the flanges of the securing rings. The timber body C is formed by wedges cut to the proper angle and pressed together by machinery ; while under pressure they are cut truly cylindrical, and in a conical form, to suit the bevel and size of the inside periphery of the tire. The body is afterwards tightly thrust into the tire by hydraulic pressure, after which the securing rings are fixed (one at each side), with their endless flanges placed into the grooves of the tire, and bolted laterally through the timbers, thus, by their great strength (being combined, and on the edge), securing that safety, &c., previously alluded to. The cheeks of the boss are tightly screwed against the sides of the timber, the centre is bored to suit the size of the axle, and the wheel is completed.

Observation.—In the year 1849 a tire on one of these wheels was cut into three distinct pieces, and worked under a waggon in that condition for nearly twelve months as an experiment prior to an introduction of the system on the South Eastern Railway, where they are now almost in general use. There are at the present time several thousands of them working on that and other lines of railway in the United Kingdom, and their safety and economy are confirmed by the practical experience of 6½ years' wear and tear. During that period a few (about four) unsound tires have broken while *en route*, but such were safely allowed to proceed without delay or inconvenience to the trains. The economy of wear and tear in these wheels has been found very considerable when compared with iron-spoked wheels

INDEX.

THE END.

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